Can globalization outweigh free-riding?

Bogmans, C.W.J.

2011

Faculty of Economics and Business Administration

Can globalization outweigh free-riding?

Research Memorandum 2011-48

Christian Bogmans

vrije Universiteit *amsterdam*

Can Globalization Outweigh Free-Riding?*

Christian Bogmans†

October 4, 2011

Abstract

We analyze the relationship between trade and the environment in a vertically integrated world economy, an international market structure that deserves further scrutiny given its empirical relevance. Next to the traditional free-riding incentive, we find that the stringency of environmental policy is influenced by terms-of-trade externalities and spillback externalities, where the latter refers to the lack of an incentive by domestic policymakers to fully internalize the international welfare effects of leakage. Moreover, these externalities are magnified if the degree of vertical integration increases. In our setting, carbon leakage is always negative and we find that globalization, as defined as an increase in (i) trade openness and (ii) the degree of vertical integration, has an ambiguous impact on the responsiveness of pollution to local environmental policy. Finally, stronger input-output linkages can mitigate the negative impact of increased openness to trade on global environmental quality.

Keywords: Globalization, Trade and Environment, Carbon leakage, Climate Policy, Input-Output.

JEL classification: F18, Q56, Q58.

*This paper is a revised version of chapter 5 of my 2011 Ph.D thesis. Without any implications, I would especially like to thank Cees Withagen and Sjak Smulders for their support and feedback while writing this paper; discussions with Aart de Zeeuw, Gerard van der Meijden, Thomas Michielsen and Peter van Oudheusden also contributed to improve this paper. I also received valuable comments and suggestions from seminar participants at the EAERE 2011 conference in Rome. Any remaining errors are mine.

†Department of Spatial Economics, VU University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, the Netherlands. Tel.: +31 20 59 86190 ; fax: +31 20 59 86004. *E-mail address*: c.w.j.bogmans@vu.nl

1 Introduction

The nature of international trade is changing. Since the middle of the 1980s trade in intermediate goods has become one of the major features of the world economy. In addition to this trend most countries have experienced an increase in the degree to which their exports are produced with imported inputs[1]. Together, these two elements play a central role in the emergence of a global economy that, to an increasing extent, is characterized by vertical integration. The objective of this paper is to determine whether these relatively recent developments in the ongoing process of globalization shed new light on the relationship between international trade and the environment. To this end, we set up a simple multi-country general equilibrium model that captures the key elements of cross-country vertical integration. In this setting several interesting results are obtained. For example, contrary to conventional wisdom we find that unilateral climate change policy results in negative carbon leakage. Thus, accounting for vertical integration seems relevant.

Recent research in the trade literature suggests that the process of globalization has occurred in two consecutive waves. According to Baldwin (2006), *'the first unbundling allowed the spatial separation of factories and consumers. The second unbundling spatially unpacked the factories and offices themselves'*. Figure 1 shows the empirical relevance of his statements: since the end of the 1980s trade in intermediate goods and business services have increased to a far greater extent than total trade (WTO, 2008). According to Yeats (2001) intermediate input trade, or 'global production sharing', already accounted for roughly thirty percent of world trade in manufacturing goods in 1995[2].

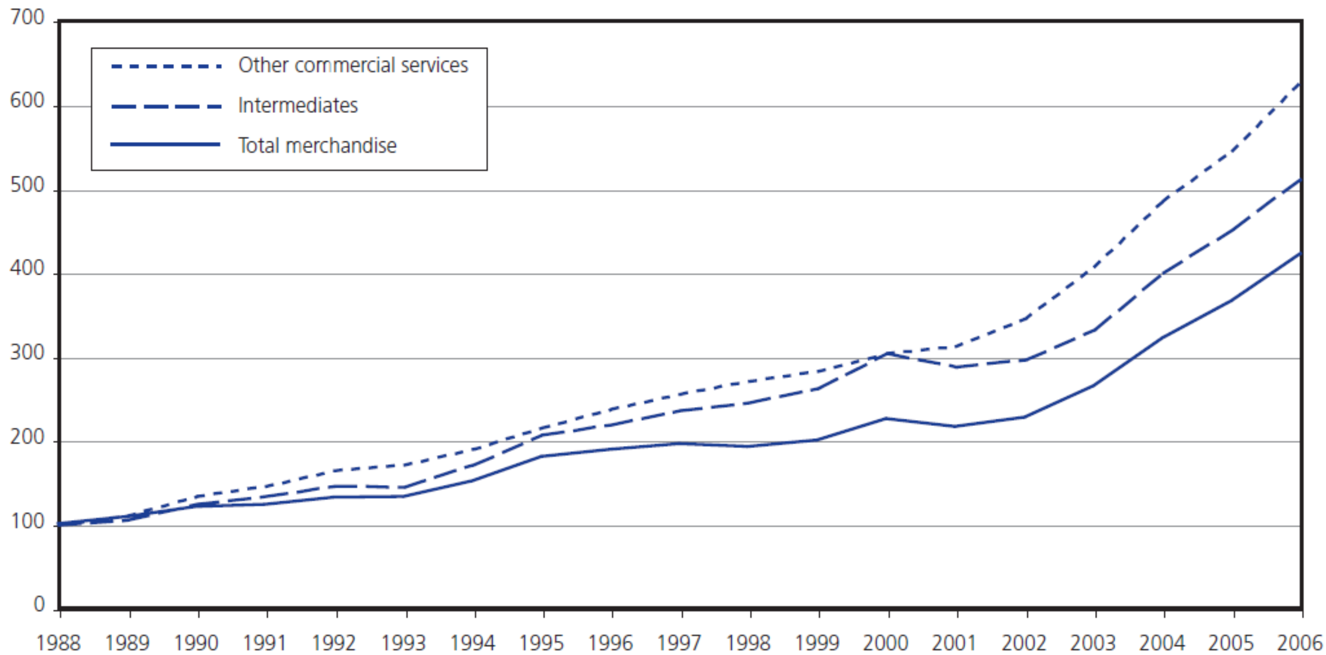

Figure 1. Trends in world trade of total merchandise, intermediate goods and commercial services.
Source : WTO (2008). Note: Intermediates are classified as in Yeats (2001).

Amidst these structural changes there has been a growing concern that trade liberalization will intensify regulatory competition in environmental policies between countries, thereby provoking a race to the

[1]Note that trade in intermediate goods does not necessarily lead to an increase in the degree to which exports are produced with imported inputs. The reason is that in principle imported intermediate goods could be used to produce non-tradable goods only. This is the case in the models by Acemoglu & Ventura (2002) and Benarroch & Weder (2006).

[2]For a more thorough overview of empirical studies in the field see Antras & Staiger (2008).

bottom (see Ederington (2010)). In this respect, trade liberalization could have negative consequences for global environmental quality. In an institutional context where the WTO and its members have taken the lead in banning the use of most trade instruments, fear for such a race to the bottom does not seem irrational. This does not represent a necessary outcome, however, as some have argued that there might be a race to the top instead. If the elasticity of demand for domestic products on world markets is sufficiently low, a significant fraction of the costs of environmental policy can be passed through to foreigners via higher prices. This incentive is stronger the larger the portion of trade that crosses national borders. Based on this argument, McAusland and Millimet (2011) explain how international trade can thus be more beneficial for the environment than intranational trade.

Of course, there is a substantial amount of theoretical research that tries to determine whether trade, directly or indirectly, results in environmental degradation. The usual method of analysis here is to compare levels of pollution under autarky and under international trade, conditional on various forms of environmental policy. So far the literature has focused on this approach while other, equally relevant aspects of globalization have received fairly little attention or have been ignored altogether. In this paper we consider a novel aspect of globalization, that is, (i) the degree of vertical integration across countries in the context of trade in intermediate goods, which we complement with (ii) the degree of trade openness, a more familiar notion of globalization. Like trade liberalization, vertical integration represents a form of economic integration, but the latter is more relevant in the context of input markets. This brings us to the main question of our paper: *can the interdependency created by vertical integration outweigh free-riding between nation states in the case of transboundary pollution*? We show that an increase in the degree of vertical integration increases the range of parameter values for which non-cooperation leads to inefficiently high levels of environmental standards. In addition, input-output linkages de facto reduce global pollution and thereby limit some of the negative effects induced by free-riding under non-cooperative policymaking. The implication of these results is that the increasing interconnectedness between countries in manufacturing industries might lead to better environmental outcomes (i.e. green welfare) in a world where non-cooperative approaches to environmental policy remain important.

The rest of this chapter is set up as follows. In the next section, we contrast our approach with the existing literature and preview some of our results. In section 3 we discuss the characteristics of our trade model. In section 4 we discuss the relationship between environmental policy, terms-of-trade effects, TFP effects and spillback effects, which forms the core of our analysis. This discussion is followed by a typology of the various determinants of global pollution in section. Here, we also explain how negative carbon leakage can arise in our model. Section 6 then compares the social optimum to the non-cooperative Nash equilibrium. We analyze various properties of the Nash equilibrium and carefully spell out the implications for global environmental quality. In section 7 we explain how globalization can erode the possibility of nation states to effectively control local environmental quality. We then move on to discuss the effects of strengthening the international input-output structure and consider the effects of decentralization on global welfare and green welfare in section 8. The last section concludes.

2 Literature Overview

The environmental consequences of trade in intermediate goods are relatively unexplored in the literature on trade and the environment. Some important exceptions are Benarroch and Weder (2006), McAusland (2004) and Hamilton and Requate (2004). Hamilton and Requate (2004) examine strategic environmental policy in a partial equilibrium model where exports are produced in a vertically related industry structure with a downstream and upstream sector. They conclude that if vertical contracts are allowed, the optimal environmental tax that should be levied on the polluting input is actually a Pigouvian tax. Our work is similar in the sense that we are interested in non-cooperative environmental policy in the presence of a vertical production structure. Unlike their paper, we consider international vertical structures instead of intranational vertical structures. Other important differences are our focus on general equilibrium and the input-output structure of production. Similar to our analysis, dirty intermediate goods are a central element of McAusland (2004), but her focus is more specific, i.e. environmental regulation as export promotion of an industry that is subject to economies of scale. Our focus is on non-cooperative policies in a vertically integrated world economy instead of unilateral policies for a small open economy. Benarroch and Weder (2006) consider a two-country model of trade in intermediate goods with monopolistic competition. They only consider pollution from final goods, abstract from optimal environmental policies and do not consider input-output linkages.

From a regulatory point of view, one can argue that international trade decouples the costs of environmental policy from the benefits of environmental policy when compared to a situation of autarky or interregional trade. This is because trade affects the costs, not the benefits, of environmental regulation if a certain fraction of domestically produced goods is exported. Two conditions are crucial for our argument. First, when determining the stringency of environmental regulation, the domestic regulator only internalizes the costs of environmental policy in as far they are borne by domestic producers and consumers. Second, export demand should be sufficiently inelastic such that the burden of environmental regulation falls on importers as well. Provided these conditions are met, the costs of environmental policy will fall with trade intensity. Therefore, stringent environmental policy will be easier for smaller than for large countries because ceteris paribus trade intensity is smaller for the latter. This beneficial aspect of policymaking in open economies is coined 'regulatory decoupling' by McAusland and Millimet (2011). Related themes are explored by Pflüger (2001), who finds that openness leads to stricter environmental regulation via consumer price spillovers in a model of monopolistic competition, and Haupt (2006), who extends this work to a setting with an endogenous number of varieties. We differentiate from the beforementioned contributions by connecting the tax-exporting motive to the degree of vertical integration and examining the consequences for (green) welfare.

With respect to our model structure, there exists a substantial literature on vertical integration, intermediate goods and international trade. Yi (2003) uses a two-country dynamic Ricardian trade model to explain how trading (un)processed intermediate goods back and forth between countries can lead to magnification of the impact of tariffs on final goods prices. We show that this intermediate goods multiplier has important consequences for the effects of environmental policy. Two characteristics of a vertically integrated world economy, as in Yi (2003), stand out. First of all, vertical specialization requires countries to specialize in certain stages of the production sequence of a final good. Second, Hummels et al. (2001) note that vertical specialization occurs when imported intermediate goods are used to produce export goods. We refer to these features of the vertically integrated world economy respectively as (i) supply chain specialization and (ii) the dependence of exports on imported inputs. Here we take a simple approach to the vertically integrated world economy. First, we assume that each country produces a unique set of tradable intermediate goods. In turn, the total set of world intermediates can be combined to form a composite intermediate good. In this way we capture supply chain specialization. Second, we assume that tradable intermediate goods are produced with domestic labor and the composite intermediate good, thereby capturing the dependence of exports on imported inputs.

3 The Model

The world consists of N countries indexed by $j = 1, 2, .., N$. In each country there are three sectors, producing (1) tradable intermediate goods, (2) a composite intermediate good and (3) a non-tradable final consumption good. In this respect the production structure is identical to Acemoglu and Ventura (2002). We extend their production structure by assuming that a composite intermediate good is not only used as an input to the final goods sector, but also serves as an input in the production of tradable intermediates. In this sense the model is similar to Rodriguez-Clare (2007) and Ramondo and Rodriguez-Clare (2010), who also assume an international input-output (I-O) structure.[1]

There exists a continuum of tradable intermediate goods with mass M. We assume that country j produces a unique subset n_j from this set of varieties with $\sum_{j=1}^{j=N} n_j = M$ and $n_j \cap n_k = \emptyset$ for $\forall j, k$ conditional on $j \neq k$. Again, we assume symmetry such that $n_j = n = \frac{M}{N}$. The assumption that each country produces a unique set of intermediates is simplifying, but captures the idea of supply chain specialization, a critical feature of the vertically integrated economy model.

There is only one (primary) factor of production, labor L, that is supplied inelastically and immobile between countries, but perfectly mobile domestically. Countries engage in two-way trade in intermediate products in order to produce a composite intermediate good. Each country produces a non-tradable final consumption good using labour and the composite intermediate good. The composite intermediate good is also used to produce the tradable intermediates (input-output). We assume that the production process of tradable intermediates is polluting and that abatement can reduce the emission intensity of production. The model is different from most trade models by assuming (i) a large number of symmetric countries, (ii) trade in intermediate goods, (iii) an I-O structure and (iv) emissions from the production of intermediate goods. Assumptions (ii)-(iv) capture our focus on a vertically integrated world economy whereas assumption (i) is adopted because it simplifies the analysis considerably.

3.1 Welfare and Consumption

The size of the world population equals L^w. We assume that each individual supplies one unit of labour and that all countries are identical in terms of population size. Under full employment total effective labor supply in each country then equals $\frac{L^w}{N} \equiv L$. Per capita welfare u in country j is determined by consumption and pollution in the following manner:

$$u(c_j, Z_j) = \frac{c_j^{1-\sigma}}{1-\sigma} - \eta Z_j \ , \ \sigma > 0 \tag{1}$$

where $c_j \equiv C_j/L$ is per-capita consumption of the aggregate consumption good in country j and Z_j is the total pollution flow experienced by citizens in country j. Pollution emitted and pollution experienced by a particular country are not necessarily equal due to spillovers between countries. Let ϕ_{ij} denote the fraction of pollution emitted by country i that spills over to country j. Then pollution experienced by country j is defined as $Z_j = nz_j + \sum_{i \neq j} \phi_{ij} nz_i$ where nz_i is pollution generated by production of intermediate goods in country i. The marginal damage from (transboundary) pollution η is assumed to be constant. In what follows we will also assume that the spillovers between countries are pairwise symmetric and equal across all country pairs, that is, $\phi_{ij} = \phi_{ji} = \phi$ for all i, j where $i \neq j$. The special cases of $\phi = 0$ and $\phi = 1$ are used to denote respectively the degree of spillovers associated with local pollutants (sulfur) and global pollutants (carbon).

[1] Note that Rodriguez-Clare (2007) and Ramondo and Rodriguez-Clare (2010) do not consider optimal policies.

3.2 Production of Intermediate Goods

The production of tradable intermediate goods requires the input of labour and a composite intermediate good. This last assumption captures the idea that a vertically integrated world economy is characterized by an (international) I-O structure. Under constant returns to scale and imposing a Cobb-Douglas functional form, the production function of a typical tradable intermediate good in country j is given by

$$y_j = (1-\theta_j) {l_{jy}}^{\beta} {x_{jy}}^{1-\beta} \tag{2}$$

where y_j refers to net output, x_{jy} represents the input of the composite tradable intermediate good in the production of a typical intermediate in country j and l_{jy} is the amount of labour employed in the production of a typical variety in country j. With each country producing n intermediates, which are produced with identical technologies (see 2), we can define $X_{jy} \equiv n x_{jy}$ and $L_{jy} \equiv n l_{jy}$ as respectively the total input of the composite intermediate good and labour in the production of tradable intermediate goods.

The production of one *net* unit of output generates $e(\theta_j)$ units of pollution, where θ_j is the fraction of gross output of the intermediate good used for abatement in country j.[3] Note that this implies that $(1-\theta_j)$ in (2) is the ratio of net output over gross output. Following Copeland and Taylor (2003) we assume a simple iso-elastic specification for the emission intensity, $e(\theta_j) \equiv (1-\theta_j)^{\frac{1-\alpha}{\alpha}}$ with $0 < \alpha < 1$. Total emissions z_j of a typical variety in country j then equal:

$$z_j = e(\theta_j) y_j \tag{3}$$

A change in θ_j will now affect z_j in three different ways: once directly through e_j, once directly via the reduction in net output y_j and indirectly via the aggregate intermediate good term ${x_{jy}}^{1-\beta}$. Alternatively, one might write total pollution of a typical variety in country j as $z_j = (1-\theta_j)^{\frac{1}{\alpha}} {l_{jy}}^{\beta} {x_{jy}}^{1-\beta}$, where $(1-\theta_j)^{\frac{1}{\alpha}}$ represents the emission intensity per gross unit of output. We assume the government is able to indirectly control the intensity of abatement θ_j by imposing an emission standard $\bar{s}_j = e(\bar{\theta}_j)$ (firm standard), where $\bar{\theta}_j$ is uniquely determined by $\bar{\theta}_j = e^{-1}(\bar{s}_j)$. An increase in θ_j works as an increase in the net unit-input requirement. The emission intensity per unit of output is strictly decreasing in the production standard, that is, $e'(\theta_j) < 0$. In the remaining of this chapter we will always refer to θ_j when discussing the stringency of environmental policy in country j.

The composite intermediate good is produced under constant returns to scale with a roundabout production technology using all available intermediate goods, which are imported from world markets. Total production of the composite intermediate good X_j follows a CES function,

$$X_j = \left(\sum_{i=1}^{N} n y_{ij}^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} \quad , \quad \varepsilon > 1 \tag{4}$$

where y_{ij} is the input of a typical intermediate good from country i in country j, representing an import in case $i \neq j$. The parameter ε is the elasticity of substitution between tradable intermediates. It also represents the price elasticity of foreign demand for the country's products and Acemoglu and Ventura (2002) interpret the inverse of this elasticity as a measure of the degree of specialization.

Markets for tradable intermediate goods are characterized by a large number of producers and a large number of buyers from the final goods sector (and the composite intermediate goods sector), and are therefore subject to perfect competition. Perfect competition and constant returns to scale together

[3] The assumption that dirty sectors use a fraction of their own output to abate pollution is common in the literature on trade and the environment. A notable expection is Greaker & Rosenknut (2008). Greaker & Rosenknut (2008) introduce a seperate upstream pollution abatement sector in a partial equilibrium trade model.

imply that unit cost pricing prevails:

$$p_j = \frac{1}{\psi}\frac{1}{1-\theta_j} {w_j}^{\beta} {P_X}^{1-\beta} \tag{5}$$

where $\psi \equiv \beta^{\beta}(1-\beta)^{1-\beta}$, w_j represents the domestic wage rate and P_X is the price of the composite intermediate good. Profit maximization by producers of the composite intermediate good results in the following price P_X which due to free trade is independent of j:

$$P_X = [\sum_{i=1}^{i=N} n{p_i}^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}} \tag{6}$$

As can be seen from (2) and (5), a direct consequence of a lower emission standard θ is a decrease in "total factor productivity" (Hicks neutral technical change) and an increase in the price of net output.

3.3 Production of the Final Good

The non-tradable consumption good is produced with (i) the composite intermediate good and (ii) labour. The final good production function reads:

$$C_j = \chi {L_{jC}}^{1-\tau} {X_{jC}}^{\tau} \tag{7}$$

where C_j is the output of the consumption good, X_{jC} is the input of the aggregate intermediate good, L_{jC} is the input of labour in the production of the consumption good and $\chi \equiv \tau^{\tau}(1-\tau)^{1-\tau}$ represents a parameter used for normalization.

With perfectly competitive markets the price of the final good is given by:

$$p_{jC} = {w_j}^{1-\tau} {P_X}^{\tau} \tag{8}$$

Market clearing for the composite intermediate good in each country requires $X_j = X_{jC} + X_{jy}$. Next, we turn to solve for factor market equilibrium from the balanced trade condition.

3.4 Global Environmental Quality

To derive total pollution emitted and "received" in a given country, we use the definition of pollution $Z_j = nz_j + \phi n \sum_{i \neq j} z_i$, and substitute for total pollution per variety z_j from (3). This leads to the following specification for total pollution:

$$Z_j = n\left[e(\theta_j)(1-\theta_j){l_{jy}}^{\beta}{x_{jy}}^{1-\beta} + \phi \sum_{i \neq j} e(\theta_i)(1-\theta_i){l_{iy}}^{\beta}{x_{iy}}^{1-\beta}\right] \tag{9}$$

Total pollution depends on environmental policy at home and abroad and the inputs of labor and the composite intermediate good in the production of intermediate goods. Once we have solved for the market equilibrium of the model, we will return to an in-depth analysis of (9), where we will take into account the endogeneity of the various inputs. As we will explain, the IO-structure of our model is of particular interest here.

3.5 Market Equilibrium and Trade Balance

In equilibrium the sum of labour employed in the production of tradable intermediates L_{jy} and the non-tradable consumption good L_{jC} should equate the supply of labour:

$$L = L_{jy} + L_{jC} \tag{10}$$

Let us define E as world expenditures on intermediates. Demand for each tradable intermediate q_j is of the constant elasticity form,

$$q_j = p_j{}^{-\varepsilon} P_X^{\varepsilon-1} E = p_j{}^{-\varepsilon} E \tag{11}$$

The second equality in (11) follows after taking P_X as the numeraire. Next, we examine in more detail world expenditures on intermediates. To this end, let us define nominal income in country j as $I_j = w_j L$. Then in all countries (i) final goods producers spend a fraction τ of total costs on intermediates and (ii) intermediate goods producers also spend a fraction $1-\beta$ of total costs on the aggregate intermediate good such that $E = \tau I^w + (1-\beta)(\sum_{j=1}^{j=N} n p_j q_j)$ where $I^w \equiv \sum_{j=1}^{j=N} I_j$ represents world income. Equilibrium in the final goods market requires that consumption expenditures equal nominal income, that is, $p_{jC} C_j = I_j$.

Next, we want to rewrite (11) in order to obtain the balanced trade condition. In the appendix we display two alternative methods to derive this condition. Let use the abbreviations IM_j and EX_j to refer to imports and exports of intermediate goods by country j. With n intermediate produced by each country and a total number of $N-1$ trading partners, imports and exports are defined as:

$$IM_j = n(p_1 y_{1j} + p_2 y_{2j} + ... + p_{j-1} y_{j-1,j} + p_{j+1} y_{j+1,j} + ... + p_N y_{Nj}) \tag{12}$$

$$EX_j = n(p_j y_{j1} + p_j y_{j2} + ... + p_j y_{j,j-1} + p_j y_{j,j+1} + ... + p_j y_{jN}) \tag{13}$$

Using these definitions of imports and exports (12)-(13) we can show that $IM_j = \frac{\tau}{\beta} I_j (1 - \frac{I_j}{I^w})$ and $EX_j = n p_j^{1-\varepsilon} \frac{\tau}{\beta}(1 - \frac{I_j}{I^w}) I^w$, where the import ratio or export ratio $\frac{IM_j}{I_j} = \frac{EX_j}{I_j} = \frac{\tau}{\beta}(1 - \frac{I_j}{I^w})$ is decreasing in relative income $\frac{I_j}{I^w}$. Equating imports and exports then leads to the balanced trade condition:

$$I_j = n p_j{}^{1-\varepsilon} I^w \tag{14}$$

where we divided by $\frac{IM_j}{I_j}$ on both sides of the equation. Thus, the left-hand side and right-hand side of (14) represent respectively imports and exports divided by the import ratio. Under balanced trade the import ratio is half the trade intensity, which equals $v_j \equiv \frac{EX_j + IM_j}{I_j} = 2\frac{\tau}{\beta}(1 - \frac{I_j}{I^w})$[4]. With symmetric countries it then follows immediately that $v = 2\frac{N-1}{N}\frac{\tau}{\beta}$. Acemoglu and Ventura (2002) obtain $v = 2\tau$, which can be obtained as a special case in our model when $\beta = 1$ (no I-O structure) and $\lim N \to \infty$[5].

4 Environmental Policy, Terms-of-Trade and I-O linkages

The division of the world into N symmetric countries allows us to define N as the 'degree of decentralization' or, alternatively, define $1/N$ as 'the degree of centralization. The degree of decentralization under symmetry ranges from 1 to ∞, which corresponds respectively to a situation of autarky ($N = 1$)

[4]One can now also show that $1-\beta$ is a measures of vertical specialization, e.g. the degree to which exports are produced with imports, since $\frac{\left(\frac{X_{jy}}{X_j}\right) IM_j}{EX_j} = 1 - \beta$.

[5]Similarly, "openness" in our setting equals $\frac{N-1}{N}\frac{\tau}{\beta}$ instead of τ in the model by Acemoglu & Ventura (2002).

and the small open economy case ($N \to \infty$). In what follows we will refer to small (large) countries when analyzing a situation where N is a relatively large (small) number, such that population size per country $\frac{L^w}{N}$ is relatively small (large). Thus, decentralization refers to a world where the number of countries N is large, population size per country is small and trade intensity $\frac{\tau}{\beta}\frac{N-1}{N}$ per country is high (and converges to $\frac{\tau}{\beta}$ in the small open economy case). Next, we analyze the effects of a unilateral marginal change in domestic environmental policy on wages and prices. The results obtained will prove to be useful when deriving the non-cooperative Nash equilibrium.

We use subscript A to denote variables of the country that marginally changes its environmental policy and we use subscript B to denote all other countries. Ex-ante countries are asymmetric so we write world income as $I^w = I_A + (N-1)I_B = w_A L + (N-1)w_B L$. From the point of view of country A all other countries are identical, hence the grouping of other countries under B. Analogously with the definitions related to income, prices of intermediate goods in country A and the other countries are given by $p_A = \frac{1}{\psi}\frac{1}{1-\theta_A}w_A{}^{\beta}$ and $p_B = \frac{1}{\psi}\frac{1}{1-\theta_B}w_B{}^{\beta}$ respectively. Substitution of these equations into (6) and (14) gives us the following set of two equations in $\{w_A, w_B, \theta_A, \theta_B\}$:

$$1 = n\left(\frac{w_A{}^{\beta}}{1-\theta_A}\right)^{1-\varepsilon} + (N-1)n\left(\frac{w_B{}^{\beta}}{1-\theta_B}\right)^{1-\varepsilon} \tag{15}$$

$$w_A L = n\left(\frac{w_A{}^{\beta}}{1-\theta_A}\right)^{1-\varepsilon}\left[w_A L + (N-1)w_B L\right] \tag{16}$$

To analyze the effect of a marginal change in the emission standard on domestic and foreign, we differentiate the price index numeraire equation (15) and the balanced trade equation (16) with respect to θ_A, the own wage rate w_A and the foreign wage rates w_B while taking θ_B as constant (see the appendix for a full derivation).

Define $p^0 \equiv \frac{w}{1-\theta}$ as the 'raw price' of the intermediate good when there is no I-O structure ($\beta = 1$) and define the effective price elasticity with respect to environmental policy ε_P as $\varepsilon_P \equiv \lim_{N->\infty}(\frac{dp_A}{d\theta_A}\frac{1-\theta_A}{p_A})$. Using this definition we find, as shown in the appendix, that $\varepsilon_P = \frac{1}{1+\beta(\varepsilon-1)}$. We are now ready to state the first set of results, all related to a unilateral marginal change in environmental policy:

Result 1 *More stringent environmental policy reduces the domestic wage rate,*

$$\frac{dw_j}{d\theta_j} = \left[\underbrace{\frac{1}{\beta}(1-\frac{1}{N})\varepsilon_P}_{ToT} \underbrace{-\frac{1}{\beta}}_{TFP}\right] p^0 = (a-b)p^0 < 0,$$

via a negative TFP effect ($-bp^0 < 0$) and a positive terms-of-trade effect ($ap^0 > 0$), where $a \equiv \frac{1}{\beta}(1-\frac{1}{N})\varepsilon_P = \frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}$ and $b \equiv \frac{1}{\beta}$ denote respectively the terms-of-trade coefficient and the TFP coefficient. Foreign wages are affected as well via terms-of-trade spillovers, $\frac{dw_i}{d\theta_j} = -\frac{1}{N-1}ap^0 < 0$. Prices of intermediate goods increase at home and decrease abroad, $\frac{dp_j}{d\theta_j} = \beta a\frac{p}{1-\theta} > 0$ and $\frac{dp_i}{d\theta_j} = -\beta\frac{1}{N-1}a\frac{p}{1-\theta} < 0$.

Environmental policy affects the return to labour via two different channels. First, there is a TFP effect. We use the term TFP effect, because producers require more inputs to produce one net unit of output if the stringency of environmental policy increases. A higher standard effectively works as a negative TFP effect that lowers the real wage, $\frac{d}{d\theta_j}(\frac{w_j}{p_{jC}}) = \frac{d}{d\theta}(w_j)^{\tau} = \tau w_j^{\tau-1}\frac{dw_j}{d\theta_j} < 0$, where the negative sign follows directly from result 1. Second, since countries produce a unique set of varieties a part of the costs of environmental policy is translated into higher prices, i.e. positive terms-of-trade effects. The degree to which depends on the elasticity ε_P and the export share of production ($\frac{N-1}{N}$). The overall impact of these two effects on the wage rate is unambiguously negative since the positive terms-of-trade effect is always overwhelmed by the negative TFP effect (Result 1).

In what way do I-O linkages change the impact of environmental policy on prices of wages? Consider first the case of a large number of small open economies where $N \to \infty$. For a small open economy one can ignore changes in foreign wages when determining the impact of a change in θ_A on w_A[6]. The introduction of I-O linkages changes the price elasticity with respect to environmental policy ε_P. Note that for $\beta = 1$ we find that ε_P equals the inverse of the elasticity of demand ε. Therefore one might interpret ε_P as the inverse of the *effective* price elasticity of demand ε_D, that is, $\varepsilon_D \equiv \frac{1}{\varepsilon_P} = 1 + \beta(\varepsilon - 1)$, where effective refers to the indirect changes in demand that result from the interlinkages between production of intermediate goods and the composite intermediate good. So why is the effective elasticity of demand smaller in the presence of an I-O structure? Intermediate goods are now even more "important" than before, as evident by the share $1 - \beta$ that intermediate good producers spend themselves on other intermediate goods. Thus, with I-O linkages it becomes more difficult to substitute away towards other (local) inputs.

To yield further insights into the general case with $N \in [1, \infty)$, we can can rearrange $\frac{dw_j}{d\theta_j} = (a - b)p^0$ to highlight the separate effects of N and β:

$$\frac{dw_j}{d\theta_j} = \underbrace{\left(-p^0 + \frac{1}{\varepsilon}p^0\right)\left(1 + \frac{(1-\beta)(\varepsilon-1)}{1+\beta(\varepsilon-1)}\right)}_{\text{small open economy}} - \frac{1}{N}\frac{1}{\beta}\frac{1}{\varepsilon}p^0\left(\frac{\varepsilon}{1+\beta(\varepsilon-1)}\right) \tag{17}$$

where the first term on the left-hand side coincides with the effect for a small open economy ($N \to \infty$). In the small open economy the opportunity cost of abatement equals $-p$, that is, the value of foregone output. There is also a terms-of-trade effect that depends on the inverse of the elasticity of demand (see Johnson (1953)). This terms-of-trade effect is strictly proportional to $\frac{1}{\varepsilon}$ when there are no I-O linkages ($\beta = 1$). Large countries have to take into account that they consume a non-negligible portion of domestically produced dirty intermediates, hence the second term on the right-hand side of (17). Conclusively, the marginal effect of abatement on the domestic wage rate can be decomposed in a TFP effect (invariant to the degree of centralization) and a terms-of-trade effect which explains that, dependent on country size, countries may export a part of the costs of environmental policy by imposing higher prices ($\frac{dp_j}{d\theta_j} > 0$ and $\frac{dp_i}{d\theta_j} < 0$). Furthermore,

Result 2 *Boomerang mechanism of environmental policy.*
The terms-of-trade effect and the TFP effect are monotonically increasing in the so-called 'intermediate goods multiplier' $\frac{1}{\beta} \in [1, \infty)$.

A useful interpretation of β can be given by noting that $1/\beta$ represents the intermediate goods multiplier of environmental policy[7]. Intuitively, a higher standard in country A means less production of the intermediate goods produced in A. Ceteris paribus, a lower supply of intermediate goods from A will also lower the total supply of the composite intermediate good. A decrease in the supply of the composite intermediate good then feeds back into the intermediate goods sector and lowers output in this sector. Diminished output of intermediate goods sets in motion a new round with reduced outputs in all sectors. This cycle will repeat itself again and again. The culmination of this cycle is the geometric

[6] In practice this means that one can differentiate the balanced trade condition (16) with respect to θ_A and w_A, while ignoring the price index equation (15).

[7] In an I-O model of a small open economy with multiple factors of production, Jones (2010) explains how the simple I-O multiplier is a special case of a general, more complex multiplier where industries differ in the degree to which rely on the inputs of intermediate goods. Furthermore, using the 2006 edition of the OECD I-O database he concludes that for most countries "one over one minus the intermediate goods share" represents a good approximation to the true multiplier.

sequence $1 + (1-\beta) + (1-\beta)^2 + .. = \frac{1}{1-(1-\beta)} = \frac{1}{\beta} \geq 1$ which holds for any $\beta \in (0,1]$. We find that both the positive terms-of-trade effect and the negative TFP effect of a higher standard are proportional to the intermediate goods multiplier (Result 2). The explanation for this multiplier follows directly from the previous argument. A stricter emission standard means that more gross output is directed to cleaning-up activities, i.e. abatement, which ceteris paribus leads to a lower supply of the intermediate good. In turn, this lowered supply means less of the composite intermediate good as well, which feeds back in the global production process of all intermediate goods and so on.

Result 3 *Terms-of-trade effects of stricter environmental policy are larger when the degree of decentralization increases,* $\frac{da}{dN} = \frac{d}{dN}(\frac{1}{\beta}\frac{N-1}{N}\varepsilon_P) = \frac{1}{\beta}\frac{1}{N^2}\varepsilon_P > 0$. *Stated otherwise, the beneficial terms-of-trade effect that lowers the costs of environmental policy is increasing with the number of countries.*

In the context of traditional trade theories based on (comparative advantage and) homogeneous goods it is well-known that big countries have an incentive to use environmental policy to influence the terms-of-trade. An importer of dirty goods can use an environmental tax that exceeds marginal damage to increase the terms-of-trade vis-à-vis dirty goods exporters. A surprising implication of our set-up is that terms-of-trade effects are actually *smaller* not larger for big countries.[8] To see why, note that the terms-of-trade coefficient, $a = \frac{1}{\beta}\frac{N-1}{N}\varepsilon_P$, is increasing in the number of countries N. This property is not unique to our setting and applies to other models, such as the monopolistic competition model of Krugman (1980), as well. With an increase in trade intensity a greater part of the costs of environmental policy will be borne by foreign consumers via higher product prices (result 3). In other words, if a large part of production is consumed outside the country the incentive for domestic policymakers to impose more stringent environmental policy on domestic firms increases. Then, for any required reduction in the level of emissions, the domestic costs are decreasing with trade intensity.

5 Global Pollution and I-O linkages

5.1 Determinants of Global Pollution

In this section we want to clarify the relationship between I-O linkages and global pollution. To do so, we derive closed-form solutions to the production of (i) the composite intermediate good and (ii) the intermediate good. Demand for intermediate i by country j follows directly from (11) and is given by $y_{ij} = p_i^{-\varepsilon}X_j = p_i^{-\varepsilon}\frac{\tau}{\beta}I_j$, where the second equality follows from $X_j = X_{jy} + X_{jC} = \frac{1-\beta}{\beta}\tau I_j + \tau I_j = \frac{\tau}{\beta}I_j$ (see the derivation of the balanced trade condition in the appendix). Subsequently, world demand for each intermediate good equals $y_i = \sum_{j=1}^{N} y_{ij} = p_i^{-\varepsilon}\frac{\tau}{\beta}I^w$. These two demand functions can then be used to derive that

$$\lambda_j \equiv \frac{y_{ij}}{y_i} = \frac{I_j}{I^w} \tag{18}$$

which tells us that a country's consumption share (or import share) of a typical intermediate good λ_j equals relative income $\frac{I_j}{I^w}$. In equilibrium we have $I_j = I$ and $I^w = NI$ such that $\lambda_j = \frac{1}{N}$. The next step is to substitute for $y_{ij} = \lambda_j y_i$ in (4) in order to obtain $X_j = nx_j = \lambda_j(\sum_i ny_i^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$. Then we substitute for all y_i from (2) in this result, using $x_{jy} = \frac{1-\beta}{n}X_j$ and $\frac{X_i}{X_j} = \frac{\lambda_i}{\lambda_j}$, and rearrange:

$$X_j = \frac{n}{1-\beta}\left(\frac{1-\beta}{n}\lambda_j G_j\right)^{\frac{1}{\beta}} l_y = \lambda_j \frac{n}{1-\beta}\left(\frac{1-\beta}{n}G\right)^{\frac{1}{\beta}} l_y \tag{19}$$

[8] Remember, when referring to large countries we refer to a world with a small number of countries.

where $G_j \equiv (\sum_i n((1-\theta_i)(\frac{\lambda_i}{\lambda_j})^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}} = \lambda_j^{\beta-1}G$. Equation (19) determines X_j as a function of relative income, labour endowment (via $l_y = \frac{\tau L}{n}$) and a world aggregate TFP term G. This composite term G represents an income weighted average of global environmental policies. A stricter domestic pollution standard spills over to other countries via this composite technology term.

Next, we substitute $x_{jy} = \frac{1-\beta}{n}X_j$, (19) and (2) into (3) in order to derive total pollution per variety:

$$z_j = e(\theta_j)(1-\theta_j)\left[\lambda_j\left(\frac{1-\beta}{n}G\right)^{\frac{1}{\beta}}\right]^{1-\beta} l_y \tag{20}$$

Under full symmetry we can write (20) as $z(\theta) = \bar{z}(1-\theta)^{\Phi}$, where $\bar{z} \equiv \left(\frac{1}{N}\frac{1-\beta}{n}M^{\frac{\varepsilon}{\varepsilon-1}}\right)^{\frac{1-\beta}{\beta}} l_y$ and $\Phi \equiv \frac{(1-\alpha)\beta+\alpha[1-(1-\tau)(1-\sigma)]}{\alpha\beta} > 0$. One could interpret Φ loosely as the elasticity of (global) pollution with respect to the share of inputs used for productive purposes (i.e. non-abatement activities), that is, $\frac{dz}{d(1-\theta)}\frac{1-\theta}{z} = \Phi$. Finally, we retrieve (world) pollution by substitution of (20) into (9) and using $nl_y = \tau\frac{L^w}{N}$:

$$Z_j = \frac{1}{N}\left[e(\theta_j)(1-\theta_j)\left(\lambda_j\right)^{1-\beta} + \phi\left(\sum_{i\neq j} e(\theta_i)(1-\theta_i)\left(\lambda_i\right)^{1-\beta}\right)\right]\left(\frac{1-\beta}{n}G\right)^{\frac{1-\beta}{\beta}} \tau L^w \tag{21}$$

Equation (21) shows clearly how pollution Z_j depends (indirectly) on global environmental policies and the world income distribution, that is, $Z_j = Z_j(\theta_1, \theta_2, .., \theta_N, \lambda_1, \lambda_2, .., \lambda_N)$. Using the tools developed by Grossman and Krueger (1993) and Copeland and Taylor (1994) we can qualitatively describe the determinants of pollution:

1. *Scale effect*. An increase in world population L^w leads to a proportional increase in world pollution.
2. *Composition effect*. (i) Since only the production of the tradable intermediate goods generates pollution, τ can be interpreted as the expenditure share on dirty goods. (ii) The term $\left(\lambda_j\right)^{1-\beta}$ captures a global composition effect : production of the (composite) intermediate good in country j expands with relative income.
3. *Technique effect*. (i) A higher standard θ_i decreases the emission intensity $e(\theta_i)(1-\theta_i)$ per gross unit of output. (ii) Global TFP in the intermediate goods sector, as measured by G, depends negatively on an income weighted-average of environmental policies.

Note that I-O linkages thus give rise to two additional effects, a novel composition effect and a novel technique effect.

5.2 Weak Links & Negative Carbon Leakage

Now that we have determined an expression for equilibrium pollution in the presence of I-O linkages (20), we are interested in the impact of a unilateral marginal change in environmental policy on equilibrium pollution, both at home and abroad. From the perspective of the mitigating country we can write domestic pollution and foreign pollution, using (20), as:

$$\begin{aligned} z_A &= e(\theta_A)(1-\theta_A)\left[\lambda_A\left(\frac{1-\beta}{n}G\right)^{\frac{1}{\beta}}\right]^{1-\beta} l_y \\ z_B &= e(\theta_B)(1-\theta_B)\left[\lambda_B\left(\frac{1-\beta}{n}G\right)^{\frac{1}{\beta}}\right]^{1-\beta} l_y \end{aligned} \tag{22}$$

where $G = (n((1-\theta_A)(\lambda_A)^{1-\beta} + (N-1)(1-\theta_B)(\lambda_B)^{1-\beta})^{\frac{\varepsilon-1}{\varepsilon}})^{\frac{\varepsilon}{\varepsilon-1}}$, $\lambda_A = \frac{I_A}{I^w}$ and $\lambda_B = \frac{I_B}{I^w}$. Let us define carbon leakage as the increase in emissions outside the country taking actions related to mitigation and define the following elasticities, $\varepsilon_{z,\theta} \equiv -\frac{dz_j}{d\theta_j}\frac{1-\theta_j}{z_j} = \frac{1}{\alpha}(1-\alpha(1-\beta)(a-b)) > 0$ and $\varepsilon^l_{z,\theta} \equiv -\frac{dz_i}{d\theta_j}\frac{1-\theta_j}{z_i} = (1-\beta)\frac{a}{N-1} > 0$, where superscript l is a mnemonic for leakage[9]. Now totally differentiate (22), subject to the definitions of G, λ_A and λ_B, with respect to θ_A, w_A and w_B, taking θ_B as given. Even though income shares will be independent of environmental policy in equilibrium due to our symmetric set-up ($\lambda_j = \frac{1}{N}$), ex-ante countries will take into account that they can affect relative income.[10] We can then state the following result:

Proposition 1 *Under a unilateral marginal increase in the stringency of environmental policy:*
1) pollution is affected by (i) a weak link effect and (ii) a global technology effect. The weak link effect decreases pollution at home but increases pollution abroad. The global technology effect decreases pollution in all countries.
2) pollution is reduced at home, that is, $\frac{dz_j}{d\theta_j} = -\varepsilon_{z,\theta}\frac{z}{1-\theta} < 0$.
3) (carbon) leakage is negative, $\frac{dz_i}{d\theta_j} = -\varepsilon^l_{z,\theta}\frac{z}{1-\theta} < 0$ *if and only if* $\beta < 1$. *There is zero leakage* ($\frac{dz_i}{d\theta_j} = 0$) *if there is no I-O structure* ($\beta = 1$).

To understand these results, consider the following interpretation of the global technology effect. Like physical capital, intermediate goods are produced inputs. If a country reduces its supply of intermediate goods, imports of these goods by trading partners will fall. This reduction of imports represents a reduction of inputs and ceteris paribus output in the importing country must decrease. As a result, pollution in the intermediate goods sector diminishes. Since the global technology effect affects all countries alike, domestic environmental policy thus results in a positive spillback effect in the form of reduced pollution abroad.

The weak link effect on the other hand describes a substitution effect and induces more (less) pollution abroad (at home): if productivity in the intermediate goods sector in one country decreases, then it follows from (19) that the 'intake' of intermediate goods in all other countries increases since it is more efficient to 'fuel' the more productive sectors. Thus, the weak link effect tells us that a decrease in the supply of intermediate goods from one country is softened by an increase in supply abroad[11].

Taken together, pollution decreases at home since both the weak link effect and the global technology effect diminish pollution in the mitigating country. In the rest of the world the weak link effect raises pollution, but the global technology effect reduces pollution. The net effect, however, on pollution in the rest of the world is always negative.

Unilateral policy resulting in negative carbon leakage is an interesting outcome. Most studies on climate change policies in open economies find the opposite result of positive leakage. As far as we know, Fullerton et al. (2011) is the only other paper that finds negative leakage[12]. In their model it results from a so-called abatement resource effect; by increasing its demand for the internationally mobile clean factor of production, the regulated sector in the mitigating country crowds out production in the unregulated sector abroad. Similar to Fullerton et al. (2011) we do not claim that carbon leakage actually is negative. The results obtained here merely illustrate that conventional models might have overlooked certain channels. Note that one could easily introduce positive carbon leakage by modi-

[9]Note that these elasticities are evaluated in the symmetric equilibrium.
[10]Only in a world with small open economies ($N \to \infty$) will policymakers ignore this effect.
[11]Jones (2011) uses the phrase 'weak link' in a closed economy I-O model to explain how complementarities in a production chain can explain income differences between countries via misallocations of production factors. The weak link effect described here is somewhat different in that (i) we focus on international I-O links and (ii) we assume that intermediates are imperfect substitutes.
[12]In contrast to our study, Fullerton et al. (2011) do not consider strategic interaction between countries nor do they derive welfare results in the context of non-cooperative policies.

fying our basic set-up. For example, one could assume pollution in other sectors or assume a more complicated production function for final goods.

6 Environmental Policy in the Global Economy

6.1 A Variety of Externalities

Before we analyze the Nash equilibrium and the social optimum in more detail, it is helpful to list the various externalities that are present in our framework:

1. *Local pollution externality.* Firms do no take into account, unless corrective policy is in place, that the production of intermediate goods pollutes the (local) environment.

2. *Transboundary pollution externality.* Firms (and governments) do not take into account that pollution spillovers from domestic production reduce welfare in other countries.

3. *Terms-of-trade externality.* Governments take into account that a higher standard raises prices of inputs for domestic producers, but ignore the fact that price increases also fall on intermediate good producers and final good producers in other countries. Thus, they ignore the negative ramifications of higher prices on welfare in other countries.

4. *Spillback externality.* A higher domestic standard affects pollution in the rest of the world through the weak link effect and the global technology effect (see proposition 1). Governments do not internalize the implications of these indirect effects for welfare in other countries.

Given these different types of externalities, how then is the non-cooperative standard distorted? First of all, the implications of (1)-(2) are obvious. In the absence of global coordination on environmental policy, (1)-(2) tends to result in too much pollution from a social planner perspective. Second, ignoring price spillovers from domestic environmental policy can actually lead to too little pollution (3). Third and finally, (4) needs some additional explanation before proceeding to the analysis of the Nash equilibrium. The impact of environmental policy on the productivity term G in the tradable goods sector can be categorized as a negative technology spillover. This negative technology spillover will ceteris paribus decrease pollution in other countries, which in turn lowers pollution spillovers to the domestic country. We refer to this additional effect as a *spillback* effect, similar to Ogawa and Wildasin (2009), and it tends to raise the optimal standard. However, since countries will only internalize this spillback effect in as much it lowers their own pollution damages there is a tendency for too much pollution[13]. For future reference, we loosely define free riding as the joint incentive underlying pollution policy as shaped by both the spillback externality and the transboundary pollution externality.

6.2 The Social Optimum

Before proceeding to the analysis of the social optimum we feel some remarks with respect to the utility function are in order. In this section and the next we focus on solutions with log-utility ($\sigma = 1$). Under different circumstances ($\sigma \neq 1$), there is a very strong tendency for the (non-cooperative) standard to increase when β decreases due to income effects[14]. Since we are not directly interested in the impact of

[13] In this sense, the spillback externality can also be interpreted as an extension to the transboundary pollution externality.

[14] To see why, we derive an implicit equation for the wage rate as a function of domestic environmental policy and foreign wages by rewriting the balanced trade condition (14) to:

$$(w_j)^{1+\beta(\varepsilon-1)} - n(1-\theta_j)^{\varepsilon-1} w_j = n(1-\theta_j)^{\varepsilon-1} (\sum_{i \neq j} w_i) \tag{23}$$

income on the stringency of environmental regulation, we decide to adopt a log-utility function such that the marginal cost of meeting the domestic standard (MAC) will not depend on the wage rate.

Let us define global welfare by $u^w \equiv \sum_{j=1}^{N} u_j$. Then substitution of (1), $c_j = \frac{w_j}{p_{jC}} = w_j^\tau$ and (21) into u^w leads to

$$V^w = \sum_{i=1}^{N} \log w_i^\tau - \eta \sum_{i=1}^{N} Z_i(\theta_1, \theta_2, .., \theta_N, \lambda_1, \lambda_2, .., \lambda_N) \tag{25}$$

To ease comparison with the non-cooperative equilibrium, we decide to analyze the market implementation of the social optimum where each country selects a standard that equates the social marginal cost of abatement to the social marginal benefit of abatement[15]. We maximize (25) with respect to θ_j, and rearrange to obtain:

$$\underbrace{-\tau\left(\frac{1}{w_j}\frac{dw_j}{d\theta_j} + (N-1)\frac{1}{w_i}\frac{dw_i}{d\theta_j}\right)}_{\equiv MAC_j^S} + \underbrace{\eta n\left(\frac{dZ_j}{d\theta_j} + (N-1)\frac{dZ_i}{d\theta_j}\right)}_{\equiv -MB_j^S} = 0 \tag{26}$$

where $\frac{dZ_j}{d\theta_j} = \frac{dz_j}{d\theta_j} + \phi(N-1)\frac{dz_i}{d\theta_j}$ and $\frac{dZ_i}{d\theta_j} = \frac{dz_i}{d\theta_j} + \phi\frac{dz_j}{d\theta_j} + \phi(N-2)\frac{dz_i}{d\theta_j}$. The first term on the left-hand side represents the social marginal cost of meeting the standard in util terms with a minus sign in front of it, that is, $MAC_j^S = -\tau\frac{1}{w_j}\frac{dw_j}{d\theta_j}$. A higher standard reduces wages at home and abroad, thereby reducing consumption and utility in all countries. The second term represents the marginal benefit of setting a standard or the marginal reduction in pollution damages from a higher standard. The marginal benefit of setting a higher standard in country j results from less pollution damages at home, which consist of a direct effect via $\frac{dz_j}{d\theta_j}$ and a spillback effect via $\phi(N-1)\frac{dz_i}{d\theta_j}$. In addition there are benefits in all other $N-1$ countries consisting of a direct leakage effect via $\frac{dz_i}{d\theta_j}$ and indirectly due to various spillovers via $\phi\frac{dz_j}{d\theta_j} + \phi(N-2)\frac{dz_i}{d\theta_j}$. Before we present the solution to the optimal standard in the social optimum θ^S, we analyze the non-cooperative problem.

6.3 The Symmetric Nash Equilibrium

For the non-cooperative Nash equilibrium the problem of country $j = 1, .., N$ is to maximize $V_j = \log w_j^\tau - \eta Z_j(\theta_1, \theta_2, .., \theta_N, \lambda_1, \lambda_2, .., \lambda_N)$ with respect to θ_j taking the standards set by other countries as given. The solution θ_j^{NC} satisfies the following first-order condition

$$\underbrace{-\tau\frac{1}{w_j}\frac{dw_j}{d\theta_j}}_{\equiv MAC_j} \underbrace{+\eta n\frac{dZ_j}{d\theta_j}}_{\equiv -MB_j} = 0 \tag{27}$$

for all $j = 1, .., N$ with $\frac{dZ_j}{d\theta_j} = \frac{dz_j}{d\theta_j} + \phi(N-1)\frac{dz_i}{d\theta_j}$. Like the social planner, each country will set the marginal cost of meeting the domestic standard (first term) equal to the marginal benefits of meeting the

When countries are fully symmetric wages must equalize and (23) boils down to:

$$w = [(1-\theta)M^{\frac{1}{\varepsilon-1}}]^{\frac{1}{\beta}} \tag{24}$$

Keep in mind that w does not depend on σ. Now from (24) note first that $\lim_{\beta\to 0} w = \lim_{\beta\to 0}[(1-\theta)M^{\frac{1}{\varepsilon-1}}]^{\frac{1}{\beta}} = +\infty$ if $(1-\theta)M^{\frac{1}{\varepsilon-1}} > 1$. Provided this is the case one also finds, using (1), that $\lim_{\beta\to 0}\frac{\partial u}{\partial c} = (w_j)^{-\sigma\tau} = 0$. In words, the marginal utility of consumption goes to zero. As we will see later on, unless we take a log-functional form for utility, the marginal cost of abatement will then go to zero as well when we strengthen the international I-O structure (lower β).

[15] Note that in the presence of international trade it is not sufficient to use private marginal cost of abatement (as it would be under autarky). Via trade a part of the costs from environmental policy automatically spill over to other countries in the form of higher prices.

domestic standard (second and third term) when determining the optimal standard. Unlike the social planner, however, individual countries do not internalize the various externalities as listed at the beginning of this section. Now let us introduce the following notation:

Definition 1. *(i) In the symmetric non-cooperative equilibrium the marginal cost of meeting the domestic standard and the marginal benefits of meeting the domestic standard in each country can be defined as functions of N, that is,* $MAC(N) = \Omega^C(N)\frac{1}{1-\theta}$ *and* $MB(N) = \Omega^B(N)(1-\theta)^{\Phi-1}$*, where* $\Omega^C(N) \equiv -\tau(a-b)$ *and* $\Omega^B(N) \equiv \eta n(\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta})\bar{z}$ *denote the MAC-coefficient and MB-coefficient respectively.*
(ii) *For the social optimum we define* $MAC^S(N) = \Omega^C_S(N)\frac{1}{1-\theta}$ *and* $MB^S(N) = \Omega^B_S(N)(1-\theta)^{\Phi-1}$ *with* $\Omega^C_S = \Omega^C(1) = \tau b$ *and* $\Omega^B_S(N) = \Omega^B(N) + (N-1)\Omega^B_l(N)$*, where* $\Omega^B_l(N) \equiv \eta n \left[\phi(\varepsilon_{z,\theta} + (N-2)\varepsilon^l_{z,\theta}) + \varepsilon^l_{z,\theta}\right]\bar{z}$.

From (26) and (27), while making use of definition 1, we can now obtain closed-form solutions for θ^S and θ^{NC}:

$$\theta^{NC} = 1 - \left[\frac{\Omega^C(N)}{\Omega^B(N)}\right]^{\frac{1}{\Phi}} \quad , \quad \theta^S = 1 - \left[\frac{\Omega^C(1)}{\Omega^B(N) + (N-1)\Omega^B_l(N)}\right]^{\frac{1}{\Phi}} \tag{28}$$

In turn, these solutions can be used to solve for Z^S and Z^{NC} by substituting from (28) into (21). The solutions under (28) satisfy the following properties[16]:

Proposition 2 *(i) Under transboundary pollution* ($\phi > 0$) *we find* $\theta^S \gtrless \theta^{NC} \Leftrightarrow (N-1)\Omega^B_l(N)\Omega^C(N) \gtrless a\tau\Omega^B(N)$.
(ii) Under purely local pollution ($\phi = 0$) *we have* $\theta^S < \theta^{NC}$.
(iii) There exists a unique $\bar{\phi} \equiv \frac{1}{N-1}\frac{a\varepsilon_{z,\theta} + (a-b)(N-1)\varepsilon^l_{z,\theta}}{(b-a)(\varepsilon_{z,\theta} + (N-2)\varepsilon^l_{z,\theta}) - a\varepsilon^l_{z,\theta}}$ *such that* $\theta^S \gtrless \theta^{NC}$ *for all* $\phi \gtrless \bar{\phi}$ provided $\bar{\phi} \in (0, 1]$.

Proposition 3 *For* $\phi < (>)\bar{\phi}$ *we find that green welfare is higher (lower) in the non-cooperative equilibrium than in the social optimum.*

Both a race to the bottom type of result, which is typical for the tax competition literature, and a race to the top result, where standards are actually higher in the non-cooperative solution than in the social optimum, are feasible depending on various parameter values. A more detailed examination of the condition under (i) might prove to be insightful here. A comparison of the two solutions under (28) tells us that the marginal cost of meeting the standard are smaller under non-cooperation than in the social optimum, which is strictly due to the terms-of-trade externality. Based on this argument alone, the non-cooperative standard should be more stringent than the standard in the social optimum. On the other hand, the marginal benefits of meeting the environmental standard are larger in the social optimum, which is due to the internalization of the transboundary pollution externality and the spillback externality. These effects work through the term $(N-1)\Omega^B_l(N)$ and they tend to make the socially optimal standard higher than the non-cooperative standard. Thus, when the terms-of-trade externality overwhelms the free-riding externality we obtain a race to the top result ($\theta^S < \theta^{NC}$) otherwise we obtain a race to the bottom result ($\theta^S > \theta^{NC}$).

If pollution spillovers between countries are absent *(*$\phi = 0$*)* non-cooperation always leads to a race to the top. How can we explain this result using our list of cross-country externalities? First, note that free-riding between nation states does not play any role when pollution is purely local. Second, under non-cooperation countries do not internalize the pollution spillback effects from a stringent standard that

[16]Note that θ^S is still a function of N since the marginal benefits of abatement depend on N: we have assumed that $\phi \in [0, 1]$ such that ceteris paribus a more decentralized world leads to lower damages.

positively affect welfare in other countries; these spillback effects are more important when I-O linkages are strong and the number of countries increases. Third, countries impose production standards to raise the terms-of-trade. It can be shown that the terms-of-trade effect always outweighs the spillback effect and a race to the top ensues.

Part (iii) of proposition 2 shows that there exists a threshold value $0 < \bar{\phi} \leq 1$ for the spillover coefficient such that for all $\phi < (>)\bar{\phi}$ we obtain a race to the top (race to the bottom) result. Although it is difficult to prove analytically, numerical analysis indicates that $\bar{\phi}$ is decreasing in β. In words, the strength of the I-O structure of the world economy increases the range of values of ϕ for which the non-cooperative standard leads to inefficiently high levels of environmental protection. Finally, from the definition of $\bar{\phi}$ we note that even with transboundary pollution it is possible that green welfare is highest in the non-cooperative equilibrium provided $\phi < \bar{\phi}$.

7 Desensitization of Pollution & Interdependence Sovereignty

In this section we are interested in the relationship between decentralization and the marginal benefits of meeting the domestic standard. The reasons for our interest are twofold. First, I-O linkages introduce new channels through which N affects the marginal benefits of environmental policy (i.e. spillback effects). Second, decentralization is of interest from an empirical perspective as well. In recent decades economic growth in numerous developing countries has lead to a decrease of the income share of the traditional economic superpowers in world GDP, giving rise to a new multipolar world economy. Essentially, decentralization changes the magnitude of the various externalities that influence non-cooperative policymaking, thereby capturing a key aspect of the before mentioned trend in global economic development.

To commence our formal analysis, total differentiation of $\Omega^B \equiv \eta(\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta})(n\bar{z})$ with respect to N leads to:

$$\frac{d}{dN}(\Omega^B) = \frac{\Omega^B}{\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta}} \frac{d(\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta})}{dN} + \frac{\Omega^B}{n\bar{z}} \frac{\partial(n\bar{z})}{\partial N} < 0$$

The total derivative of Ω^B consists of two terms. The first term on the right-hand side explains how the marginal benefit of a standard increases with the elasticity of (global) pollution with respect to domestic environmental policy, $\frac{d(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^l_{z,\theta})}{dN}$, whereas the second term shows how a decrease in country size decreases pollution and in turn diminishes the marginal benefit of a standard[17]. The impact of decentralization on the marginal benefits of meeting the domestic standard is strictly negative, $\frac{d}{dN}(\Omega^B) < 0$. To explain the influence of I-O linkages in more detail, consider first the impact of decentralization on the upperbound of pollution $n\bar{z}$. From $n\bar{z} = \left((1-\beta)M^{\frac{1}{\varepsilon-1}}\right)^{\frac{1-\beta}{\beta}} \frac{\tau L^w}{N}$ we can derive that $\frac{\partial(n\bar{z})}{\partial N} = -\frac{n\bar{z}}{N} < 0$ and $\frac{\partial}{\partial\beta}\left(\frac{\partial(n\bar{z})}{\partial N}\right) < 0$. In words, if country size diminishes then pollution per country declines and this effect is stronger if the degree of I-O linkages increases (e.g. β decreases). Some interesting characteristics of the derivative of the elasticity of (global) pollution with respect to country size (decentralization) are documented in the following proposition:

Proposition 4 *Desensitization of pollution with respect to local environmental policy.*
Under decentralization ($N \uparrow$):

[17] In theory, voluntary contributions to global public goods tend to be positively correlated with country size (see Vickary (2009)) because populous countries capture a relatively large share of the benefits from their mitigation efforts. Similarly, decentralization lowers the marginal benefits of meeting the domestic standard simply because smaller countries produce less (endowment effect).

(i) pollution in any given country becomes less responsive to local environmental policy ($\frac{d\varepsilon_{z,\theta}}{dN} < 0$ *and* $\frac{d\varepsilon^{l}_{z,\theta}}{dN} < 0$*).*
(ii) the responsiveness of global pollution is (strictly) negative ($\frac{d(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^{l}_{z,\theta})}{dN} = -(1-\phi)(1-\beta)\frac{da}{dN} \leq 0$*).*
An increase in the degree of vertical integration ($\beta \downarrow$*):*
(iii) increases the responsiveness of pollution in any given country to local environmental policy ($\frac{d\varepsilon_{z,\theta}}{d\beta} < 0$ *and* $\frac{d\varepsilon^{l}_{z,\theta}}{d\beta} < 0$*).*

Decentralization affects the responsiveness of pollution with respect to local environmental regulation. The impact of any given country through environmental policy on pollution at home and in other countries diminishes ($\frac{d\varepsilon_{z,\theta}}{dN} < 0$, $\frac{d\varepsilon^{l}_{z,\theta}}{dN} < 0$ and $\frac{d(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^{l}_{z,\theta})}{dN} < 0$) when countries become smaller. These derivatives summarize what we define as *desensitization*: the marginal reduction in domestic pollution due to a higher standard becomes smaller if country size decreases (N increases). On the other hand, an increase in the degree of vertical integration leads to the opposite result of domestic pollution being more responsive to changes in domestic environmental policy. If one is willing to define globalization as increases in vertical integration and decentralization, then clearly the impact of globalization on the responsiveness of pollution is ambiguous.

In our view, proposition 4 describes an important and a somewhat overlooked aspect of environmental policy in open economies. The fact that local pollution become less responsive to local policies in a globalized world represents a separate pathway through which trade affects green welfare. To explain this effect in more detail, consider the following explanation. Refer to the sector producing the composite intermediate good as the upstream industry and the sector producing intermediate goods as the downstream industry. In any particular country, the downstream industry depends on inputs from the upstream industry and vice versa. In addition, the upstream industry depends on inputs of intermediate inputs from other countries as well. In this global web of downstream and upstream industries, the impact of environmental regulation is weakened when country size diminishes. In particular, the weak link effect and the global technology effect of a marginal change in environmental policy, as described under proposition 1, are diminished for higher degrees of decentralization.

Of course, in general one would expect the effectiveness of local (environmental) policies to be interdependent on the actions taken by other countries. The question whether a country can (effectively) exercise control over its domestic affairs is related to the concept of national sovereignty. Following Krasner (1999), Bagwell and Staiger (2004) use four distinct ways to define sovereignty in order to evaluate how sovereignty and international efficiency conflict in a two-country model of international interdependence (e.g. trade interactions). Especially relevant here is their definition of *interdependence sovereignty*, which 'refers to the scope of activities over which states can effectively exercise control' (Bagwell and Staiger, 2004). In our setting this relates to the question whether countries can effectively exercise control over local environmental quality. Proposition 4 shows us that in a globalized world countries loose control not only over domestic pollution ($\frac{d\varepsilon_{z,\theta}}{dN} < 0$), but are also faced with a decreasing impact on what happens abroad ($\frac{d\varepsilon^{l}_{z,\theta}}{dN} < 0$). Having said that, in the case of global warming ($\phi = 1$) a nation's control over global environmental quality is unaffected by globalization, that is, $\frac{d(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^{l}_{z,\theta})}{dN} = 0$. For strictly local pollutants ($\phi = 0$) one obtains the result that interdependence sovereignty is indeed increasingly diminished, $\frac{\partial(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^{l}_{z,\theta})}{\partial N} = -(1-\beta)\frac{da}{dN} < 0$. An interesting set of questions for future research is in what form desensitization is present in more general models with trade costs and whether our results are robust with respect to country asymmetries and market structure.

8 Global Welfare, Green Welfare and other properties of the Nash equilibrium

Next, let us discuss a few interesting properties of the non-cooperative standard under transboundary pollution. Our interest goes out to the impact of decentralization (N) and the impact of I-O linkages (β). First of all, analytically we find that the non-cooperative solution is ambiguous with respect to N ($\frac{d\theta^{NC}}{dN} = -\frac{1}{\Phi}\left(\frac{\Omega^C}{\Omega^B}\right)^{\frac{1}{\Phi}}\left(\frac{d\Omega^C/dN}{\Omega^C} - \frac{d\Omega^B/dN}{\Omega^B}\right) \gtrless 0$). While decentralization ($N \uparrow$) increases the extent of regulatory decoupling ($\Omega^C \downarrow$) it also exacerbates the free-riding motive ($\Omega^B \downarrow$). Using (28) we also find that stronger I-O linkages potentially lead to a higher non-cooperative standard ($\frac{d\theta^{NC}}{d\beta} \gtrless 0$). How can we explain this ambiguity? We find that the effect of a marginal change in β on the marginal cost (benefit) of meeting the domestic standard is always negative (ambiguous), that is, $\frac{d\Omega^C}{d\beta} < -\frac{1}{\beta}\frac{1}{N}b < 0$ and $\frac{d\Omega^B}{d\beta} \gtrless 0$. Even more interesting, when production technology is characterized by a strong I-O structure then the strength of the free-riding effect is possibly reduced, that is, $\frac{d}{d\beta}(\frac{d\theta^{NC}}{dN}) \lesseqgtr 0$.

To explore the ambiguity of our results in more detail, we conduct some numerical experiments. Figure 1 depicts the level of the non-cooperative standard as a function of the degree of centralization (N) and the strength of the I-O linkages (β). We take the following parameters: $\alpha = 0.3$, $\tau = 0.5$, $\varepsilon = 2$, $M = 1$, $L^w = 10$ and $\eta = 10$. The following observations stand out:

- Ceteris paribus a higher level of decentralization lowers the non-cooperative standard.
- Stronger I-O linkages reduce the non-cooperative standard.
- The negative impact of decentralization on the non-cooperative standard does not seem to be affected by the strength of the I-O structure.

The first observation tells us that, even though we have not been able to derive an analytical proof, the non-cooperative standard decreases monotonically under decentralization. We also find that a stronger I-O structure decreases the optimal standard. So far we have not been able to find parameter values that show otherwise. The third observation explains that even though in theory a stronger I-O structure could mitigate the negative effects of decentralization, our numerical experiments indicate that the overall effect is likely to be small ($\frac{\partial}{\partial \beta}(\frac{\partial \theta^{NC}}{\partial N}) \approx 0$).

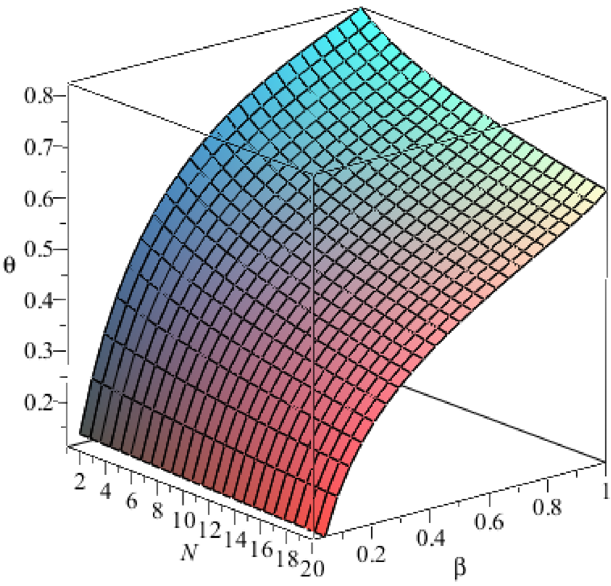

Figure 1a: The impact of decentralization & IO-linkages on the optimal standard

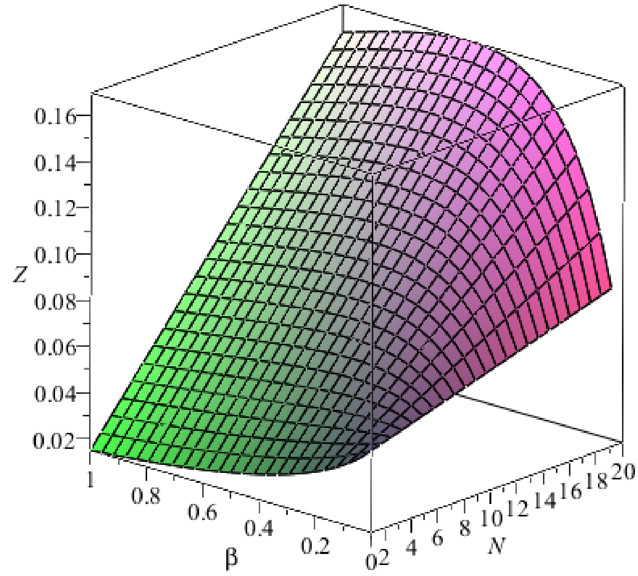

Figure 1b: Can IO-linkages reduce global pollution?

Like the equilibrium properties of the non-cooperative standard, signing the derivatives of equilibrium pollution with respect to N and β is not trivial. A change in the strength of the I-O structure of the world economy, as captured by the parameter β, affects world pollution by changing the magnitude of the various composition and technique effects that we identified; a higher β decreases emission intensity ($e(\theta) \downarrow$) and decreases the ratio of net output over gross output ($(1-\theta) \downarrow$), but has an ambiguous effect on the total input (and production) of the composite intermediate good due to a positive market share term ($\lambda^{1-\beta} \uparrow$), a positive composition effect ($(1-\beta)^{\frac{1-\beta}{\beta}} \uparrow$) and an ambiguous global technology effect ($G^{\frac{1-\beta}{\beta}} \uparrow\downarrow$). All in all, the total effect on world pollution of a change in β is ambiguous.

We depict the effects of decentralization and the strength of I-O linkages on global pollution in figure 1b. Again, the results that follow from this numerical exercise are clear. First, the level of global pollution is increasing in the degree of decentralization. As was evident from the explanation following proposition 2, this is caused by the overwhelming impact of free-riding on the willingness to reduce emissions. Second, and closely related to the previous observation, decentralization increases global pollution, but the extent to which this happens is reduced if I-O linkages are stronger (low β). Note that for high levels of decentralization the effect of β on global pollution is u-shaped: at low levels of vertical integration a decrease in β raises pollution but once β is sufficiently small further decreases actually lower pollution. Thus, even though environmental policy is less stringent when I-O linkages are stronger (see figure 1a), numerical experiments indicate that for most parameter values the effects on global pollution are actually positive: strong linkages eventually reduce pollution, especially when decentralization is high.

9 Conclusion

In countries with a high trade intensity regulators are faced with relatively low costs of abatement since part of these costs fall on foreign consumers via higher prices. In such a setting domestic policy makers might impose excessively stringent environmental policies. We extended this idea by considering I-O linkages. We were then able to analyze the implications for global pollution and global welfare. A surprising result is that in a world with trade in intermediate goods, mitigating countries do not have to worry about carbon leakage. Stringent regulation lowers the supply of intermediate goods to world markets. Since intermediate inputs, like physical capital, are produced inputs a decrease in their supply will lower pollution in the importing countries.

We also found (i) that whether global environmental quality is higher in the social optimum or the non-cooperative equilibrium depends on the degree of spillovers and (ii) that I-O linkages reduce the difference between these equilibria. Nevertheless, in case of fully transboundary pollution a race to the bottom can not be prevented, even if one is willing to assume an unrealistically strong I-O structure. Thus, in the absence of global cooperation underprovision of global environmental quality remains an important issue. Using numerical analysis we then showed that, even though I-O linkages do not outweigh the impact of free-riding on the stringency of environmental policy, these linkages effectively magnify the productivity loss that is caused by global emission standards, thereby reducing global pollution. On a somewhat different note, we were able to show that local pollution becomes less responsive to local policy in a globalized world, which represents a novel pathway through which trade affects green welfare. It was then explained that vertical integration limits this process of desensitization.

The model used in this chapter was deliberately simple, thereby allowing for a range of analytically tractable results. Future work might focus on the implications of models where specialization patterns are endogenous, as well as examining the case with an endogenous number of global varieties. Another point of interest is to repeat the analysis with asymmetric countries. Probably more interesting is a more detailed assessment of climate change policies in the presence of both international (and national) I-O structures (see Leontief (1970) and Levinson (2009)). At the industry level, more detailed analysis of sectors involving trade in intermediate goods might be a worthwhile endeavor as well[18]. This seems especially interesting in the context of certain sectors, such as energy and transportation. These sectors seem of vital importance not only to the world economy, as measured by the degree to which they are linked to other sectors in the global economy, but, since they are very carbon intensive, are also crucial for mitigation of climate change.

References

[1] Acemoglu, Daron and Ventura, Jaume (2002), 'The World Income Distribution', *The Quarterly Journal of Economics*, vol. 117 (2), pp. 659-694.

[2] Antras, Pol and Staiger, Robert W. (2008), 'Offshoring and the Role of Trade Agreements', NBER Working Paper 14285, National Bureau of Economic Research, Inc.

[3] Bagwell, Kyle and Staiger, Robert W. (2004) 'National Sovereignty in an Interdependent World', NBER Working Papers 10249, National Bureau of Economic Research, Inc.

[4] Baldwin, R. (2008), 'Globalisation: the great unbundling(s)', contribution to: *Globalisation Challenges for Europe and Finland*, Secretariat of the Economic Council of Finland.

[18] A recent paper by Lanz et al. (2011) analyses the effects of climate policies for the global copper industry, thereby emphasing the role of trade in intermediate goods and geographical considerations.

[5] Benarroch, Michael and Weder, Rolf (2006), 'Intra-industry trade in intermediate products, pollution and internationally increasing returns', *Journal of Environmental Economics and Management*, vol. 52 (3), pp. 675-689.

[6] Copeland, Brian R., Taylor, M Scott (1994), 'North-South Trade and the Environment', *The Quarterly Journal of Economics*, vol. 109 (3), pp. 755-87.

[7] Copeland, Brian R., Taylor, M Scott (2003), *Trade and the Environment: Theory and Evidence*, Princeton University Press, New Jersey.

[8] Ederington, Josh (2010), 'Should Trade Agreements Include Environmental Policy?', *Review of Environmental Economics and Policy*, vol. 4 (1), pp. 84-102.

[9] Fullerton, Don, Karney, Daniel & Baylis, Kathy (2011), 'Negative Leakage', NBER Working Papers 17001, National Bureau of Economic Research, Inc.

[10] Greaker, Mads and Rosendahl, Knut Einar (2008), 'Environmental policy with upstream pollution abatement technology firms', *Journal of Environmental Economics and Management*, vol. 56 (3), pp. 246-259.

[11] Grossman, G. and Krueger, A. (1993), 'Environmental Impacts of a North American Free Trade Agreement', in: Peter Garber, ed., *The Mexico-U.S. Free Trade Agreement*, M.I.T Press.

[12] Hamilton, S.F. & Requate, T. (2004), 'Vertical structure and strategic environmental trade policy', *Journal of Environmental Economics and Management*, vol. 47 (2), pp. 260-269.

[13] Haupt, Alexander (2006), 'Environmental Policy in Open Economies and Monopolistic Competition', *Environmental & Resource Economics*, vol. 33 (2), pp. 143-167.

[14] Hummels, David, Ishi, Jun and Yi, Kei-Mu (2001), 'The nature and growth of vertical specialization in world trade', *Journal of International Economics*, vol. 54 (1), pp. 75-96.

[15] Johnson, Harry (1953), 'Optimum Tariffs and Retaliation', *Review of Economic Studies,* vol. 21 (2), pp. 142–153.

[16] Jones, Charles (2010), 'Misallocation, Economic Growth, and Input-Output Economics', Prepared for the 10th World Congress of the Econometric Society, mimeo.

[17] Jones, Charles (2011), 'Intermediate Goods and Weak Links in the Theory of Economic Development', *American Economic Journal: Macroeconomics*, vol. 3 (2), pp. 1-28.

[18] Kei-Mu Yi (2003), 'Can Vertical Specialization Explain the Growth of World Trade?', *Journal of Political Economy*, vol. 111 (1), pp. 52-102.

[19] Krasner, Stephen D. (1999), Sovereignity: Organized Hypocrisy, Princeton University Press.

[20] Krugman, P. (1980), 'Scale Economies, Product Differentiation, and the Pattern of Trade', *American Economic Review*, 70(5), pp. 950-959.

[21] Lanz, B., Rutherford, T., and Tilton, J. (2011), 'Subglobal Climate Agreements and Energy-Intensive Activities: Is there a Carbon Haven for Copper?', MIT Center for Energy and Environmental Policy Research Working Paper 2011-003.

[22] Leontief, W. (1970), 'Environmental Repercussions and the Economic Structure: An Input-Output Approach', *The Review of Economics and Statistics*, vol. 52 (3), pp. 262-71.

[23] Levinson, A. (2009), 'Technology, International Trade, and Pollution from US Manufacturing', *American Economic Review*, vol. 99 (5), pp. 2177-92.

[24] McAusland, Carol (2004), 'Environmental Regulation as Export Promotion: Product Standards for Dirty Intermediate Goods', *The B.E. Journal of Economic Analysis & Policy*, vol. 0 (2).

[25] McAusland, Carol and Millimet, Daniel (2011), 'Do National Borders Matter? Intranational Trade, International Trade, and the Environment', mimeo.

[26] Pflüger, M. (2001), 'Ecological Dumping under Monopolistic Competition', *Scandinavian Journal of Economics*, vol. 103 (4), pp. 689-706.

[27] Ramondo, Natalia and Rodríguez-Clare, Andrés (2009), 'Trade, Multinational Production, and the Gains from Openness', NBER Working Papers 15604.

[28] Rodriguez-Clare, Andrés (2007), 'Trade, Diffusion and the Gains from Openness', NBER Working Papers 13662.

[29] Ogawa, H. and Wildasin, David E. (2009), 'Think Locally, Act Locally: Spillovers, Spillbacks, and Efficient Decentralized Policymaking', *American Economic Review*, vol. 99 (4), pp. 1206-17.

[30] Vicary, Simon (2009), 'The voluntary provision of a public good in an international commons', *Canadian Journal of Economic*s, vol. 42 (3), pp. 984–996.

[31] WTO (2008), 'World Trade Report 2008 - Trade in a Globalizing World', Geneva.

[32] Yeats, A. (2001), 'Just how big is global production sharing?', in Kierzkowski, H. and Arndt, S.W. (eds) Fragmentation: New Production Patterns in the World Economy, Oxford and New York: Oxford University Press.

10 Appendix

10.1 Proofs of Results and Propositions

Result 1 *More stringent environmental policy reduces the domestic wage rate,*

$$\frac{dw_j}{d\theta_j} = (\underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}}_{ToT} - \underbrace{\frac{1}{\beta}}_{TFP})p^0 = (a-b)p^0 < 0,$$

via a negative TFP effect ($-bp^0 < 0$) *and a positive terms-of-trade effect* ($ap^0 > 0$), *where* $a \equiv \frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}$ *and* $b \equiv \frac{1}{\beta}$ *denote respectively the terms-of-trade coefficient and the TFP coefficient. Foreign wages are affected as well via terms-of-trade spillovers,* $\frac{dw_i}{d\theta_j} = -\frac{1}{N-1}ap^0 < 0$. *Prices of intermediate goods increase at home and decrease abroad,* $\frac{dp_j}{d\theta_j} = \beta a \frac{p}{1-\theta} > 0$ *and* $\frac{dp_i}{d\theta_j} = -\beta\frac{1}{N-1}a\frac{p}{1-\theta} < 0$.

Proof Let us denote variables of the country under consideration by subscript A and use B to denote the other countries (which are ex-ante symmetric from the point of view of country A). First, we use $npq = \frac{\tau}{\beta}I$ in $(1-\beta)\int_0^M p(i)q(i)di = (1-\beta)Nnpq$ to obtain $(1-\beta)\int_0^M p(i)q(i)di = \frac{1-\beta}{\beta}\tau I^w$. Using this result, $p_A = \frac{(w_A)^\beta}{1-\theta_A}$ and $I^w = I_A + (N-1)I_B$ we can rewrite the balanced trade condition, $\tau I_A = \beta n(p_A)^{1-\varepsilon}[\tau I^w + (1-\beta)\int_0^M p(i)q(i)di]$, as:

$$w_A L = n\left(\frac{w_A{}^\beta}{1-\theta_A}\right)^{1-\varepsilon}[w_A L + (N-1)w_B L] \tag{29}$$

The price index can be represented as:

$$1 = n\left(\frac{w_A{}^{\beta}}{1-\theta_A}\right)^{1-\varepsilon} + (N-1)n\left(\frac{w_B{}^{\beta}}{1-\theta_B}\right)^{1-\varepsilon} \tag{30}$$

Total differentiation of (29) and (30) with respect to $\{w_A, w_B, \theta_A\}$, thereby taking θ_B, L_B and L_A as constant, gives us:

$$\frac{I_A}{w_A}dw_A = \frac{I_A}{I^w}(\frac{I_A}{w_A}dw_A + (N-1)\frac{I_B}{w_B}dw_B) + \beta(1-\varepsilon)\frac{I_A}{w_A}dw_A + (1-\varepsilon)\frac{I_A}{1-\theta_A}d\theta_A \tag{31}$$

$$0 = \beta\frac{L_A}{I^w}dw_A + \frac{1}{1-\theta_A}\frac{I_A}{I^w}d\theta_A + (N-1)\beta\frac{L_B}{I^w}dw_B \tag{32}$$

Rearranging (31) and noting that $L_B = L_A$ leads to:

$$dw_B = \frac{1}{(N-1)I_A}[(1+\beta(\varepsilon-1))I^w - I_A]dw_A - \frac{1}{N-1}\frac{1-\varepsilon}{1-\theta_A}\frac{I^w}{L_B}d\theta_A \tag{33}$$

Substitution of (33) into (32), evaluating in the symmetric equilibrium ($w_A = w_B$ and $\theta_A = \theta_B$) and rearranging terms then provides for the equilibrium solution:

$$\begin{aligned} \frac{dw_A}{d\theta_A} &= -\frac{1}{\beta}\frac{1}{N}\frac{1+\beta(\varepsilon-1)N}{1+\beta(\varepsilon-1)}p^0 \\ &= (\underbrace{-\frac{1}{\beta}}_{TFP} + \underbrace{\frac{1}{\beta}\frac{N-1}{N}\frac{1}{1+\beta(\varepsilon-1)}}_{ToT})p^0 \end{aligned} \tag{34}$$

Substitution of $\frac{dw_A}{d\theta_A}$ in $\frac{dp_A}{d\theta_A} = \beta\frac{p_A}{w_A}\frac{dw_A}{d\theta_A} + \frac{p_A}{1-\theta_A}$ and applying symmetry yields $\frac{dp_A}{d\theta_A} = a\frac{p}{1-\theta}$. These results can also be used to derive the effect on wages and prices in other countries. First, rewrite (33):

$$\frac{dw_B}{d\theta_A} = \frac{(1+\beta(\varepsilon-1))I^w - I_A}{(N-1)I_A}\frac{dw_A}{d\theta_A} - \frac{1}{N-1}\frac{1-\varepsilon}{1-\theta_A}\frac{I^w}{L_B} \tag{35}$$

Second, substitution of (34) into (35) yields:

$$\frac{dw_B}{d\theta_A} = \frac{dp_B}{d\theta_A} = -\left(\frac{1}{\beta}\frac{1}{N}\frac{1}{1+\beta(\varepsilon-1)}\right)p^0 = -\frac{1}{N-1}ap^0 < 0$$

Recall that by definition we must have $\frac{dp_A}{d\theta_A} + (N-1)\frac{dp_B}{d\theta_B} = 0$, which tells us that the terms-of-trade effects work purely distributive (zero-sum). This completes the proof.

Result 2 *Boomerang mechanism of environmental policy.*
The terms-of-trade effect and the TFP effect are monotonically increasing in the so-called 'intermediate goods multiplier' $\frac{1}{\beta} \in [1, \infty)$.
Proof Inspection of $\frac{dw_j}{d\theta_j}$ in (34) immediately shows that the TFP coefficient is proportional to $1/\beta$. With respect to the terms-of-trade coefficient a, differentiation shows that $\frac{da}{d(1/\beta)} = \frac{a}{1/\beta}(1+\beta\frac{\varepsilon-1}{1+\beta(\varepsilon-1)}) > 0$. This completes the proof.

Result 3 *Terms-of-trade effects of stricter environmental policy are larger when the degree of decentralization increases, $\frac{da}{dN} = \frac{d}{dN}(\frac{1}{\beta}\frac{N-1}{N}\varepsilon_P) = \frac{1}{\beta}\frac{1}{N^2}\varepsilon_P > 0$. Stated otherwise, the beneficial terms-of-trade effect that lowers the costs of environmental policy is increasing with the number of countries.*

Proof Inspection of $a - b = \left(\frac{1}{\beta}\frac{N-1}{N}\varepsilon_P - \frac{1}{\beta}\right)$ immediately shows $\frac{d(a-b)}{dN} = \frac{\partial a}{\partial N} = \frac{1}{\beta}\frac{1}{N^2}\varepsilon_P > 0$.

Proposition 1 *Under a unilateral marginal increase in the stringency of environmental policy:*
1) pollution is affected by (i) a weak link effect and (ii) a global technology effect. The weak link effect decreases pollution at home but increases pollution abroad. The global technology effect decreases pollution in all countries.
2) pollution is reduced at home, that is, $\frac{dz_j}{d\theta_j} = -\varepsilon_{z,\theta}\frac{z}{1-\theta} < 0$.
3) (carbon) leakage is negative, $\frac{dz_i}{d\theta_j} = -\varepsilon^l_{z,\theta}\frac{z}{1-\theta} < 0$ *if and only if* $\beta < 1$. *There is zero leakage (*$\frac{dz_i}{d\theta_j} = 0$*) if there is no I-O structure (*$\beta = 1$*).*
Proof (1) Total differentiation of (22) with respect to θ_A leads to

$$\frac{dz_A}{d\theta_A} = z_A\frac{e'(\theta_A)}{e(\theta_A)} - z_A\frac{1}{1-\theta_A} + \underbrace{z_A(1-\beta)\frac{1}{\lambda_A}\frac{d\lambda_A}{d\theta_A}}_{\text{weak link effect A}} + \underbrace{z_A\frac{1-\beta}{\beta}\frac{1}{G}\frac{dG}{d\theta_A}}_{\text{global technology effect}} \tag{36}$$

$$\frac{dz_B}{d\theta_A} = \underbrace{z_B(1-\beta)\frac{1}{\lambda_B}\frac{d\lambda_B}{d\theta_A}}_{\text{weak link effect B}} + \underbrace{z_B\frac{1-\beta}{\beta}\frac{1}{G}\frac{dG}{d\theta_A}}_{\text{global technology effect}} \tag{37}$$

where the last two terms on the right-hand side represent respectively the weak link effect and the global technology effect. Since $\frac{d\lambda_A}{d\theta_A} < 0$, $\frac{d\lambda_B}{d\theta_A} > 0$ and $\frac{dG}{d\theta_A} < 0$ it follows that the weak link effect in country A (B) is negative (positive) whereas the global technology effect is negative. (2) Substitution of $\frac{d\lambda_A}{d\theta_A} = \lambda_A(\frac{1}{w_A}\frac{dw_A}{d\theta_A} - \frac{1}{w_A+(N-1)w_B}(\frac{dw_A}{d\theta_A} + (N-1)\frac{dw_B}{d\theta_A}))$ and
$\frac{dG}{d\theta_A} = n^{\frac{\varepsilon}{\varepsilon-1}}\left(-\lambda_A^{1-\beta} + (1-\theta_A)(1-\beta)\lambda_A^{-\beta}\frac{d\lambda_A}{d\theta_A} + (N-1)(1-\theta_B)(1-\beta)\lambda_B^{-\beta}\frac{d\lambda_B}{d\theta_A}\right)$, using result 1, applying symmetry and using the definition of $\varepsilon_{z,\theta}$ provides us with $\frac{dz_j}{d\theta_j} = -\varepsilon_{z,\theta}\frac{z}{1-\theta} < 0$. (3) Similar to (2), substitution of $\frac{dG}{d\theta_A}$ and $\frac{d\lambda_B}{d\theta_A} = \lambda_B(\frac{1}{w_B}\frac{dw_B}{d\theta_A} - \frac{1}{w_A+(N-1)w_B}(\frac{dw_A}{d\theta_A} + (N-1)\frac{dw_B}{d\theta_A}))$ into (37), applying symmetry and using the definition of $\varepsilon^l_{z,\theta}$ gives us $\frac{dz_i}{d\theta_j} = -\varepsilon^l_{z,\theta}\frac{z}{1-\theta} < 0$. This completes the proof.

Proposition 2 *(i) Under transboundary pollution (*$\phi > 0$*) we find* $\theta^S \gtrless \theta^{NC} \Leftrightarrow (N-1)\Omega^B_l(N)\Omega^C(N) \gtrless a\tau\Omega^B(N)$.
(ii) Under purely local pollution ($\phi = 0$*) we have* $\theta^S < \theta^{NC}$.
(iii) There exists a unique $\bar{\phi} \equiv \frac{1}{N-1}\frac{a\varepsilon_{z,\theta}+(a-b)(N-1)\varepsilon^l_{z,\theta}}{-(a-b)(\varepsilon_{z,\theta}+(N-2)\varepsilon^l_{z,\theta})-a\varepsilon^l_{z,\theta}}$ *such that* $\theta^S \gtrless \theta^{NC}$ *for all* $\phi \gtrless \bar{\phi}$ provided $\bar{\phi} \in (0, 1]$.
Proof (i) Substitution of the coefficients from definition 1 into (28) results in the following expressions for the pollution standard:

$$\theta^{NC} = 1 - \left[\frac{\tau(b-a)}{\eta n(\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta})\bar{z}}\right]^{\frac{1}{\Phi}} \tag{38}$$

$$\theta^S = 1 - \left[\frac{1}{\eta n\bar{z}}\frac{\tau b}{\varepsilon_{z,\theta} + \phi(N-1)\varepsilon^l_{z,\theta} + (N-1)\left(\phi(\varepsilon_{z,\theta} + (N-2)\varepsilon^l_{z,\theta}) + \varepsilon^l_{z,\theta}\right)}\right]^{\frac{1}{\Phi}} \tag{39}$$

where $\Phi \equiv \frac{(1-\alpha)\beta+\alpha-\alpha(1-\tau)(1-\sigma)}{\alpha\beta} > 0$. Comparing these solutions shows us that
$\theta^S \gtrless \theta^{NC} \Leftrightarrow (N-1)\Omega^B_l(N)\Omega^C(N) \gtrless a\tau\Omega^B(N)$. (ii) If there are no spillovers the expression for the standard in social optimum from (39) reads $\theta^S|_{\phi=0} = 1 - \left[\frac{1}{\eta n\bar{z}}\frac{\tau b}{\varepsilon_{z,\theta}+2(N-1)\varepsilon^l_{z,\theta}}\right]^{\frac{1}{\Phi}}$. Quick inspection of θ^S and θ^{NC} some rearrangement reveals that $\theta^S < \theta^{NC} \Leftrightarrow -(a-b)(N-1)\varepsilon^l_{z,\theta} < a\varepsilon_{z,\theta} \Leftrightarrow 0 < \frac{1}{\alpha}$. (iii) From (i) we find that $\bar{\phi}$ is implicitly defined by $\theta^S = \theta^{NC}$. Rearranging leads to an explicit expression,

$\bar{\phi} \equiv \frac{1}{N-1} \frac{a\varepsilon_{z,\theta}+(a-b)(N-1)\varepsilon^l_{z,\theta}}{-(a-b)(\varepsilon_{z,\theta}+(N-2)\varepsilon^l_{z,\theta})-a\varepsilon^l_{z,\theta}}$.

Proposition 3 *For $\phi < (>)\bar{\phi}$ we find that green welfare is higher (lower) in the non-cooperative equilibrium than in the social optimum.*
Proof Since $\theta^S \gtrless \theta^{NC}$ for $\phi \gtrless \bar{\phi}$ we have $Z(\theta^S) \gtrless Z(\theta^{NC})$ for $\phi \gtrless \bar{\phi}$. This completes the proof.

Proposition 4 *Desensitization of pollution with respect to local environmental policy.*
Under decentralization ($N \uparrow$):
(i) pollution in any given country becomes less responsive to local environmental policy ($\frac{d\varepsilon_{z,\theta}}{dN} < 0$ and $\frac{d\varepsilon^l_{z,\theta}}{dN} < 0$).
(ii) the responsiveness of global pollution is (strictly) negative ($\frac{d(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^l_{z,\theta})}{dN} = -(1-\phi)(1-\beta)\frac{da}{dN} \leq 0$).
An increase in the degree of vertical integration ($\beta \downarrow$):
(iii) increases the responsiveness of pollution in any given country to local environmental policy ($\frac{d\varepsilon_{z,\theta}}{d\beta} < 0$ and $\frac{d\varepsilon^l_{z,\theta}}{d\beta} < 0$).
Proof Total differentiation of $\varepsilon_{z,\theta}$ and $\varepsilon^l_{z,\theta}$ with respect to N shows us $\frac{d\varepsilon_{z,\theta}}{dN} = -(1-\beta)\frac{da}{dN} < 0$ and $\frac{d\varepsilon^l_{z,\theta}}{dN} = -(1-\beta)\frac{1}{N-1}\frac{a}{N} = -\frac{\varepsilon^l_{z,\theta}}{N} < 0$. Using these derivatives one can show that $\frac{d(\varepsilon_{z,\theta}+\phi(N-1)\varepsilon^l_{z,\theta})}{dN} = -(1-\phi)(1-\beta)\frac{da}{dN} \leq 0$. This proofs (i) and (ii). Total differentiation of $\varepsilon_{z,\theta}$ and $\varepsilon^l_{z,\theta}$ with respect to β gives us $\frac{d\varepsilon_{z,\theta}}{d\beta} = \frac{1}{\beta}(a-b) + \frac{(1-\beta)(\varepsilon-1)}{1+\beta(\varepsilon-1)}a < \frac{1}{\beta}(a-b) + (\varepsilon-1)a = -\frac{1}{\beta}\frac{1}{N}b < 0$ and $\frac{d\varepsilon^l_{z,\theta}}{d\beta} = -\frac{a}{N-1} + \frac{1-\beta}{N-1}\frac{da}{d\beta} < 0$. This completes the proof.

10.2 Derivation of the Balanced Trade Condition

10.2.1 Direct Method

Three steps are needed. First, using (2) profit maximization in the intermediate goods sector results in:

$$w_j l_{jy} = \beta p_j y_j \quad \text{and} \quad x_{jy} = (1-\beta) p_j y_j \tag{40}$$

Second, profit maximization in the final goods sector gives us $w_j L_{jC} = (1-\tau)I_j$. Using this result, the definition of nominal income $I_j = w_j L = p_{jC}C$ and (10) we obtain

$$n w_j l_{jy} = \tau I_j \tag{41}$$

Combining (40) and (41) then provides us with expressions for l_{jy} and x_{jy} as function of parameters and domestic income, $l_{jy} = \frac{\tau I_j}{n w_j}$ and $x_{jy} = (\frac{1-\beta}{\beta})\frac{\tau I_j}{n}$, as well as being able to rewrite $\sum_{j=1}^{j=N} n p_j q_j = \sum_{j=1}^{j=N} \frac{\tau}{\beta} I_j = \frac{\tau}{\beta} I^w$. Third, we then substitute $l_{jy} = \frac{\tau I_j}{n w_j}$ and $x_{jy} = (\frac{1-\beta}{\beta})\frac{\tau I_j}{n}$ into $q_j = (1-\theta_j)(l_{jy})^\beta (x_{jy})^{1-\beta}$, which in turn we substitute for q_j on the left-hand side of the demand function (11) and finally we rearrange to get:

$$I_j = n(p_j)^{1-\varepsilon} I^w$$

which equals (14) in the main text.

10.2.2 Alternative Method

Setting imports (12) equal to exports (13), we can write

$$n p_j y_j - n p_j y_{jj} = \sum_i n p_i y_{ij} - n p_j y_{jj}$$

On the left-hand side we can substitute for $np_jy_j = np_j^{1-\varepsilon}\frac{\tau}{\beta}I^w$ and $np_jy_{jj} = np_jy_j\frac{X_j}{X^w} = np_j^{1-\varepsilon}\frac{\tau}{\beta}I_j$:

$$EX_j = np_jy_j - np_jy_{jj} = np_j^{1-\varepsilon}\frac{\tau}{\beta}(1-\frac{I_j}{I^w})I^w$$

On the right-hand side we can substitute for $\sum_i np_iy_{ij} = \frac{\tau}{\beta}I_j$ and $np_jy_{jj} = \frac{\tau}{\beta}I_j\frac{I_j}{I^w}$:

$$IM_j = \sum_i np_iy_{ij} - np_jy_{jj} = \frac{\tau}{\beta}I_j(1-\frac{I_j}{I^w})$$

Equating imports and export results in the equation obtained in the main text, $I_j = np_j^{1-\varepsilon}I^w$.

2007-1	M. Francesca Cracolici Miranda Cuffaro Peter Nijkamp	Geographical distribution of enemployment: An analysis of provincial differences in Italy, 21 p.
2007-2	Daniel Leliefeld Evgenia Motchenkova	To protec in order to serve, adverse effects of leniency programs in view of industry asymmetry, 29 p.
2007-3	M.C. Wassenaar E. Dijkgraaf R.H.J.M. Gradus	Contracting out: Dutch municipalities reject the solution for the VAT-distortion, 24 p.
2007-4	R.S. Halbersma M.C. Mikkers E. Motchenkova I. Seinen	Market structure and hospital-insurer bargaining in the Netherlands, 20 p.
2007-5	Bas P. Singer Bart A.G. Bossink Herman J.M. Vande Putte	Corporate Real estate and competitive strategy, 27 p.
2007-6	Dorien Kooij Annet de Lange Paul Jansen Josje Dikkers	Older workers' motivation to continue to work: Five meanings of age. A conceptual review, 46 p.
2007-7	Stella Flytzani Peter Nijkamp	Locus of control and cross-cultural adjustment of expatriate managers, 16 p.
2007-8	Tibert Verhagen Willemijn van Dolen	Explaining online purchase intentions: A multi-channel store image perspective, 28 p.
2007-9	Patrizia Riganti Peter Nijkamp	Congestion in popular tourist areas: A multi-attribute experimental choice analysis of willingness-to-wait in Amsterdam, 21 p.
2007-10	Tüzin Baycan-Levent Peter Nijkamp	Critical success factors in planning and management of urban green spaces in Europe, 14 p.
2007-11	Tüzin Baycan-Levent Peter Nijkamp	Migrant entrepreneurship in a diverse Europe: In search of sustainable development, 18 p.
2007-12	Tüzin Baycan-Levent Peter Nijkamp Mediha Sahin	New orientations in ethnic entrepreneurship: Motivation, goals and strategies in new generation ethnic entrepreneurs, 22 p.
2007-13	Miranda Cuffaro Maria Francesca Cracolici Peter Nijkamp	Measuring the performance of Italian regions on social and economic dimensions, 20 p.

2007-14	Tüzin Baycan-Levent Peter Nijkamp	Characteristics of migrant entrepreneurship in Europe, 14 p.
2007-15	Maria Teresa Borzacchiello Peter Nijkamp Eric Koomen	Accessibility and urban development: A grid-based comparative statistical analysis of Dutch cities, 22 p.
2007-16	Tibert Verhagen Selmar Meents	A framework for developing semantic differentials in IS research: Assessing the meaning of electronic marketplace quality (EMQ), 64 p.
2007-17	Aliye Ahu Gülümser Tüzin Baycan Levent Peter Nijkamp	Changing trends in rural self-employment in Europe, 34 p.
2007-18	Laura de Dominicis Raymond J.G.M. Florax Henri L.F. de Groot	De ruimtelijke verdeling van economische activiteit: Agglomeratie- en locatiepatronen in Nederland, 35 p.
2007-19	E. Dijkgraaf R.H.J.M. Gradus	How to get increasing competition in the Dutch refuse collection market? 15 p.

2008-1	Maria T. Borzacchiello Irene Casas Biagio Ciuffo Peter Nijkamp	Geo-ICT in Transportation Science, 25 p.
2008-2	Maura Soekijad Jeroen Walschots Marleen Huysman	Congestion at the floating road? Negotiation in networked innovation, 38 p.
2008-3	Marlous Agterberg Bart van den Hooff Marleen Huysman Maura Soekijad	Keeping the wheels turning: Multi-level dynamics in organizing networks of practice, 47 p.
2008-4	Marlous Agterberg Marleen Huysman Bart van den Hooff	Leadership in online knowledge networks: Challenges and coping strategies in a network of practice, 36 p.
2008-5	Bernd Heidergott Haralambie Leahu	Differentiability of product measures, 35 p.
2008-6	Tibert Verhagen Frans Feldberg Bart van den Hooff Selmar Meents	Explaining user adoption of virtual worlds: towards a multipurpose motivational model, 37 p.
2008-7	Masagus M. Ridhwan Peter Nijkamp Piet Rietveld Henri L.F. de Groot	Regional development and monetary policy. A review of the role of monetary unions, capital mobility and locational effects, 27 p.
2008-8	Selmar Meents Tibert Verhagen	Investigating the impact of C2C electronic marketplace quality on trust, 69 p.
2008-9	Junbo Yu Peter Nijkamp	China's prospects as an innovative country: An industrial economics perspective, 27 p
2008-10	Junbo Yu Peter Nijkamp	Ownership, r&d and productivity change: Assessing the catch-up in China's high-tech industries, 31 p
2008-11	Elbert Dijkgraaf Raymond Gradus	Environmental activism and dynamics of unit-based pricing systems, 18 p.
2008-12	Mark J. Koetse Jan Rouwendal	Transport and welfare consequences of infrastructure investment: A case study for the Betuweroute, 24 p
2008-13	Marc D. Bahlmann Marleen H. Huysman Tom Elfring Peter Groenewegen	Clusters as vehicles for entrepreneurial innovation and new idea generation – a critical assessment
2008-14	Soushi Suzuki Peter Nijkamp	A generalized goals-achievement model in data envelopment analysis: An application to efficiency improvement in local government finance in Japan, 24 p.
2008-15	Tüzin Baycan-Levent	External orientation of second generation migrant entrepreneurs. A sectoral

	Peter Nijkamp Mediha Sahin	study on Amsterdam, 33 p.
2008-16	Enno Masurel	Local shopkeepers' associations and ethnic minority entrepreneurs, 21 p.
2008-17	Frank Frößler Boriana Rukanova Stefan Klein Allen Higgins Yao-Hua Tan	Inter-organisational network formation and sense-making: Initiation and management of a living lab, 25 p.
2008-18	Peter Nijkamp Frank Zwetsloot Sander van der Wal	A meta-multicriteria analysis of innovation and growth potentials of European regions, 20 p.
2008-19	Junbo Yu Roger R. Stough Peter Nijkamp	Governing technological entrepreneurship in China and the West, 21 p.
2008-20	Maria T. Borzacchiello Peter Nijkamp Henk J. Scholten	A logistic regression model for explaining urban development on the basis of accessibility: a case study of Naples, 13 p.
2008-21	Marius Ooms	Trends in applied econometrics software development 1985-2008, an analysis of Journal of Applied Econometrics research articles, software reviews, data and code, 30 p.
2008-22	Aliye Ahu Gülümser Tüzin Baycan-Levent Peter Nijkamp	Changing trends in rural self-employment in Europe and Turkey, 20 p.
2008-23	Patricia van Hemert Peter Nijkamp	Thematic research prioritization in the EU and the Netherlands: an assessment on the basis of content analysis, 30 p.
2008-24	Jasper Dekkers Eric Koomen	Valuation of open space. Hedonic house price analysis in the Dutch Randstad region, 19 p.

2009-1	Boriana Rukanova Rolf T. Wignand Yao-Hua Tan	From national to supranational government inter-organizational systems: An extended typology, 33 p.
2009-2	Marc D. Bahlmann Marleen H. Huysman Tom Elfring Peter Groenewegen	Global Pipelines or global buzz? A micro-level approach towards the knowledge-based view of clusters, 33 p.
2009-3	Julie E. Ferguson Marleen H. Huysman	Between ambition and approach: Towards sustainable knowledge management in development organizations, 33 p.
2009-4	Mark G. Leijsen	Why empirical cost functions get scale economies wrong, 11 p.
2009-5	Peter Nijkamp Galit Cohen-Blankshtain	The importance of ICT for cities: e-governance and cyber perceptions, 14 p.
2009-6	Eric de Noronha Vaz Mário Caetano Peter Nijkamp	Trapped between antiquity and urbanism. A multi-criteria assessment model of the greater Cairo metropolitan area, 22 p.
2009-7	Eric de Noronha Vaz Teresa de Noronha Vaz Peter Nijkamp	Spatial analysis for policy evaluation of the rural world: Portuguese agriculture in the last decade, 16 p.
2009-8	Teresa de Noronha Vaz Peter Nijkamp	Multitasking in the rural world: Technological change and sustainability, 20 p.
2009-9	Maria Teresa Borzacchiello Vincenzo Torrieri Peter Nijkamp	An operational information systems architecture for assessing sustainable transportation planning: Principles and design, 17 p.
2009-10	Vincenzo Del Giudice Pierfrancesco De Paola Francesca Torrieri Francesca Pagliari Peter Nijkamp	A decision support system for real estate investment choice, 16 p.
2009-11	Miruna Mazurencu Marinescu Peter Nijkamp	IT companies in rough seas: Predictive factors for bankruptcy risk in Romania, 13 p.
2009-12	Boriana Rukanova Helle Zinner Hendriksen Eveline van Stijn Yao-Hua Tan	Bringing is innovation in a highly-regulated environment: A collective action perspective, 33 p.
2009-13	Patricia van Hemert Peter Nijkamp Jolanda Verbraak	Evaluating social science and humanities knowledge production: an exploratory analysis of dynamics in science systems, 20 p.

2009-14	Roberto Patuelli Aura Reggiani Peter Nijkamp Norbert Schanne	Neural networks for cross-sectional employment forecasts: A comparison of model specifications for Germany, 15 p.
2009-15	André de Waal Karima Kourtit Peter Nijkamp	The relationship between the level of completeness of a strategic performance management system and perceived advantages and disadvantages, 19 p.
2009-16	Vincenzo Punzo Vincenzo Torrieri Maria Teresa Borzacchiello Biagio Ciuffo Peter Nijkamp	Modelling intermodal re-balance and integration: planning a sub-lagoon tube for Venezia, 24 p.
2009-17	Peter Nijkamp Roger Stough Mediha Sahin	Impact of social and human capital on business performance of migrant entrepreneurs – a comparative Dutch-US study, 31 p.
2009-18	Dres Creal	A survey of sequential Monte Carlo methods for economics and finance, 54 p.
2009-19	Karima Kourtit André de Waal	Strategic performance management in practice: Advantages, disadvantages and reasons for use, 15 p.
2009-20	Karima Kourtit André de Waal Peter Nijkamp	Strategic performance management and creative industry, 17 p.
2009-21	Eric de Noronha Vaz Peter Nijkamp	Historico-cultural sustainability and urban dynamics – a geo-information science approach to the Algarve area, 25 p.
2009-22	Roberta Capello Peter Nijkamp	Regional growth and development theories revisited, 19 p.
2009-23	M. Francesca Cracolici Miranda Cuffaro Peter Nijkamp	Tourism sustainability and economic efficiency – a statistical analysis of Italian provinces, 14 p.
2009-24	Caroline A. Rodenburg Peter Nijkamp Henri L.F. de Groot Erik T. Verhoef	Valuation of multifunctional land use by commercial investors: A case study on the Amsterdam Zuidas mega-project, 21 p.
2009-25	Katrin Oltmer Peter Nijkamp Raymond Florax Floor Brouwer	Sustainability and agri-environmental policy in the European Union: A meta-analytic investigation, 26 p.
2009-26	Francesca Torrieri Peter Nijkamp	Scenario analysis in spatial impact assessment: A methodological approach, 20 p.
2009-27	Aliye Ahu Gülümser Tüzin Baycan-Levent Peter Nijkamp	Beauty is in the eyes of the beholder: A logistic regression analysis of sustainability and locality as competitive vehicles for human settlements, 14 p.

2009-28	Marco Percoco Peter Nijkamp	Individual time preferences and social discounting in environmental projects, 24 p.
2009-29	Peter Nijkamp Maria Abreu	Regional development theory, 12 p.
2009-30	Tüzin Baycan-Levent Peter Nijkamp	7 FAQs in urban planning, 22 p.
2009-31	Aliye Ahu Gülümser Tüzin Baycan-Levent Peter Nijkamp	Turkey's rurality: A comparative analysis at the EU level, 22 p.
2009-32	Frank Bruinsma Karima Kourtit Peter Nijkamp	An agent-based decision support model for the development of e-services in the tourist sector, 21 p.
2009-33	Mediha Sahin Peter Nijkamp Marius Rietdijk	Cultural diversity and urban innovativeness: Personal and business characteristics of urban migrant entrepreneurs, 27 p.
2009-34	Peter Nijkamp Mediha Sahin	Performance indicators of urban migrant entrepreneurship in the Netherlands, 28 p.
2009-35	Manfred M. Fischer Peter Nijkamp	Entrepreneurship and regional development, 23 p.
2009-36	Faroek Lazrak Peter Nijkamp Piet Rietveld Jan Rouwendal	Cultural heritage and creative cities: An economic evaluation perspective, 20 p.
2009-37	Enno Masurel Peter Nijkamp	Bridging the gap between institutions of higher education and small and medium-size enterprises, 32 p.
2009-38	Francesca Medda Peter Nijkamp Piet Rietveld	Dynamic effects of external and private transport costs on urban shape: A morphogenetic perspective, 17 p.
2009-39	Roberta Capello Peter Nijkamp	Urban economics at a cross-yard: Recent theoretical and methodological directions and future challenges, 16 p.
2009-40	Enno Masurel Peter Nijkamp	The low participation of urban migrant entrepreneurs: Reasons and perceptions of weak institutional embeddedness, 23 p.
2009-41	Patricia van Hemert Peter Nijkamp	Knowledge investments, business R&D and innovativeness of countries. A qualitative meta-analytic comparison, 25 p.
2009-42	Teresa de Noronha Vaz Peter Nijkamp	Knowledge and innovation: The strings between global and local dimensions of sustainable growth, 16 p.
2009-43	Chiara M. Travisi Peter Nijkamp	Managing environmental risk in agriculture: A systematic perspective on the potential of quantitative policy-oriented risk valuation, 19 p.
2009-44	Sander de Leeuw	Logistics aspects of emergency preparedness in flood disaster prevention, 24 p.

	Iris F.A. Vis Sebastiaan B. Jonkman	
2009-45	Eveline S. van Leeuwen Peter Nijkamp	Social accounting matrices. The development and application of SAMs at the local level, 26 p.
2009-46	Tibert Verhagen Willemijn van Dolen	The influence of online store characteristics on consumer impulsive decision-making: A model and empirical application, 33 p.
2009-47	Eveline van Leeuwen Peter Nijkamp	A micro-simulation model for e-services in cultural heritage tourism, 23 p.
2009-48	Andrea Caragliu Chiara Del Bo Peter Nijkamp	Smart cities in Europe, 15 p.
2009-49	Faroek Lazrak Peter Nijkamp Piet Rietveld Jan Rouwendal	Cultural heritage: Hedonic prices for non-market values, 11 p.
2009-50	Eric de Noronha Vaz João Pedro Bernardes Peter Nijkamp	Past landscapes for the reconstruction of Roman land use: Eco-history tourism in the Algarve, 23 p.
2009-51	Eveline van Leeuwen Peter Nijkamp Teresa de Noronha Vaz	The Multi-functional use of urban green space, 12 p.
2009-52	Peter Bakker Carl Koopmans Peter Nijkamp	Appraisal of integrated transport policies, 20 p.
2009-53	Luca De Angelis Leonard J. Paas	The dynamics analysis and prediction of stock markets through the latent Markov model, 29 p.
2009-54	Jan Anne Annema Carl Koopmans	Een lastige praktijk: Ervaringen met waarderen van omgevingskwaliteit in de kosten-batenanalyse, 17 p.
2009-55	Bas Straathof Gert-Jan Linders	Europe’s internal market at fifty: Over the hill? 39 p.
2009-56	Joaquim A.S. Gromicho Jelke J. van Hoorn Francisco Saldanha-da-Gama Gerrit T. Timmer	Exponentially better than brute force: solving the job-shop scheduling problem optimally by dynamic programming, 14 p.
2009-57	Carmen Lee Roman Kraeussl Leo Paas	The effect of anticipated and experienced regret and pride on investors’ future selling decisions, 31 p.
2009-58	René Sitters	Efficient algorithms for average completion time scheduling, 17 p.

2009-59	Masood Gheasi Peter Nijkamp Piet Rietveld	Migration and tourist flows, 20 p.

2010-1	Roberto Patuelli Norbert Schanne Daniel A. Griffith Peter Nijkamp	Persistent disparities in regional unemployment: Application of a spatial filtering approach to local labour markets in Germany, 28 p.
2010-2	Thomas de Graaff Ghebre Debrezion Piet Rietveld	Schaalsprong Almere. Het effect van bereikbaarheidsverbeteringen op de huizenprijzen in Almere, 22 p.
2010-3	John Steenbruggen Maria Teresa Borzacchiello Peter Nijkamp Henk Scholten	Real-time data from mobile phone networks for urban incidence and traffic management – a review of application and opportunities, 23 p.
2010-4	Marc D. Bahlmann Tom Elfring Peter Groenewegen Marleen H. Huysman	Does distance matter? An ego-network approach towards the knowledge-based theory of clusters, 31 p.
2010-5	Jelke J. van Hoorn	A note on the worst case complexity for the capacitated vehicle routing problem, 3 p.
2010-6	Mark G. Lijesen	Empirical applications of spatial competition; an interpretative literature review, 16 p.
2010-7	Carmen Lee Roman Kraeussl Leo Paas	Personality and investment: Personality differences affect investors' adaptation to losses, 28 p.
2010-8	Nahom Ghebrihiwet Evgenia Motchenkova	Leniency programs in the presence of judicial errors, 21 p.
2010-9	Meindert J. Flikkema Ard-Pieter de Man Matthijs Wolters	New trademark registration as an indicator of innovation: results of an explorative study of Benelux trademark data, 53 p.
2010-10	Jani Merikivi Tibert Verhagen Frans Feldberg	Having belief(s) in social virtual worlds: A decomposed approach, 37 p.
2010-11	Umut Kilinç	Price-cost markups and productivity dynamics of entrant plants, 34 p.
2010-12	Umut Kilinç	Measuring competition in a frictional economy, 39 p.

2011-1	Yoshifumi Takahashi Peter Nijkamp	Multifunctional agricultural land use in sustainable world, 25 p.
2011-2	Paulo A.L.D. Nunes Peter Nijkamp	Biodiversity: Economic perspectives, 37 p.
2011-3	Eric de Noronha Vaz Doan Nainggolan Peter Nijkamp Marco Painho	A complex spatial systems analysis of tourism and urban sprawl in the Algarve, 23 p.
2011-4	Karima Kourtit Peter Nijkamp	Strangers on the move. Ethnic entrepreneurs as urban change actors, 34 p.
2011-5	Manie Geyer Helen C. Coetzee Danie Du Plessis Ronnie Donaldson Peter Nijkamp	Recent business transformation in intermediate-sized cities in South Africa, 30 p.
2011-6	Aki Kangasharju Christophe Tavéra Peter Nijkamp	Regional growth and unemployment. The validity of Okun's law for the Finnish regions, 17 p.
2011-7	Amitrajeet A. Batabyal Peter Nijkamp	A Schumpeterian model of entrepreneurship, innovation, and regional economic growth, 30 p.
2011-8	Aliye Ahu Akgün Tüzin Baycan Levent Peter Nijkamp	The engine of sustainable rural development: Embeddedness of entrepreneurs in rural Turkey, 17 p.
2011-9	Aliye Ahu Akgün Eveline van Leeuwen Peter Nijkamp	A systemic perspective on multi-stakeholder sustainable development strategies, 26 p.
2011-10	Tibert Verhagen Jaap van Nes Frans Feldberg Willemijn van Dolen	Virtual customer service agents: Using social presence and personalization to shape online service encounters, 48 p.
2011-11	Henk J. Scholten Maarten van der Vlist	De inrichting van crisisbeheersing, de relatie tussen besluitvorming en informatievoorziening. Casus: Warroom project Netcentrisch werken bij Rijkswaterstaat, 23 p.
2011-12	Tüzin Baycan Peter Nijkamp	A socio-economic impact analysis of cultural diversity, 22 p.
2011-13	Aliye Ahu Akgün Tüzin Baycan Peter Nijkamp	Repositioning rural areas as promising future hot spots, 22 p.
2011-14	Selmar Meents Tibert Verhagen Paul Vlaar	How sellers can stimulate purchasing in electronic marketplaces: Using information as a risk reduction signal, 29 p.

2011-15	Aliye Ahu Gülümser Tüzin Baycan-Levent Peter Nijkamp	Measuring regional creative capacity: A literature review for rural-specific approaches, 22 p.
2011-16	Frank Bruinsma Karima Kourtit Peter Nijkamp	Tourism, culture and e-services: Evaluation of e-services packages, 30 p.
2011-17	Peter Nijkamp Frank Bruinsma Karima Kourtit Eveline van Leeuwen	Supply of and demand for e-services in the cultural sector: Combining top-down and bottom-up perspectives, 16 p.
2011-18	Eveline van Leeuwen Peter Nijkamp Piet Rietveld	Climate change: From global concern to regional challenge, 17 p.
2011-19	Eveline van Leeuwen Peter Nijkamp	Operational advances in tourism research, 25 p.
2011-20	Aliye Ahu Akgün Tüzin Baycan Peter Nijkamp	Creative capacity for sustainable development: A comparative analysis of European and Turkish rural regions, 18 p.
2011-21	Aliye Ahu Gülümser Tüzin Baycan-Levent Peter Nijkamp	Business dynamics as the source of counterurbanisation: An empirical analysis of Turkey, 18 p.
2011-22	Jessie Bakens Peter Nijkamp	Lessons from migration impact analysis, 19 p.
2011-23	Peter Nijkamp Galit Cohen-blankshtain	Opportunities and pitfalls of local e-democracy, 17 p.
2011-24	Maura Soekijad Irene Skovgaard Smith	The 'lean people' in hospital change: Identity work as social differentiation, 30 p.
2011-25	Evgenia Motchenkova Olgerd Rus	Research joint ventures and price collusion: Joint analysis of the impact of R&D subsidies and antitrust fines, 30 p.
2011-26	Karima Kourtit Peter Nijkamp	Strategic choice analysis by expert panels for migration impact assessment, 41 p.
2011-27	Faroek Lazrak Peter Nijkamp Piet Rietveld Jan Rouwendal	The market value of listed heritage: An urban economic application of spatial hedonic pricing, 24 p.
2011-28	Peter Nijkamp	Socio-economic impacts of heterogeneity among foreign migrants: Research and policy challenges, 17 p.
2011-29	Masood Gheasi Peter Nijkamp	Migration, tourism and international trade: Evidence from the UK, 8 p.
2011-30	Karima Kourtit	Evaluation of cyber-tools in cultural tourism, 24 p.

	Peter Nijkamp Eveline van Leeuwen Frank Bruinsma	
2011-31	Cathy Macharis Peter Nijkamp	Possible bias in multi-actor multi-criteria transportation evaluation: Issues and solutions, 16 p.
2011-32	John Steenbruggen Maria Teresa Borzacchiello Peter Nijkamp Henk Scholten	The use of GSM data for transport safety management: An exploratory review, 29 p.
2011-33	John Steenbruggen Peter Nijkamp Jan M. Smits Michel Grothe	Traffic incident management: A common operational picture to support situational awareness of sustainable mobility, 36 p.
2011-34	Tüzin Baycan Peter Nijkamp	Students’ interest in an entrepreneurial career in a multicultural society, 25 p.
2011-35	Adele Finco Deborah Bentivoglio Peter Nijkamp	Integrated evaluation of biofuel production options in agriculture: An exploration of sustainable policy scenarios, 16 p.
2011-36	Eric de Noronha Vaz Pedro Cabral Mário Caetano Peter Nijkamp Marco Paínho	Urban heritage endangerment at the interface of future cities and past heritage: A spatial vulnerability assessment, 25 p.
2011-37	Maria Giaoutzi Anastasia Stratigea Eveline van Leeuwen Peter Nijkamp	Scenario analysis in foresight: AG2020, 23 p.
2011-38	Peter Nijkamp Patricia van Hemert	Knowledge infrastructure and regional growth, 12 p.
2011-39	Patricia van Hemert Enno Masurel Peter Nijkamp	The role of knowledge sources of SME’s for innovation perception and regional innovation policy, 27 p.
2011-40	Eric de Noronha Vaz Marco Painho Peter Nijkamp	Impacts of environmental law and regulations on agricultural land-use change and urban pressure: The Algarve case, 18 p.
2011-41	Karima Kourtit Peter Nijkamp Steef Lowik Frans van Vught Paul Vulto	From islands of innovation to creative hotspots, 26 p.
2011-42	Alina Todiras Peter Nijkamp Saidas Rafijevas	Innovative marketing strategies for national industrial flagships: Brand repositioning for accessing upscale markets, 27 p.

2011-43	Eric de Noronha Vaz Mário Caetano Peter Nijkamp	A multi-level spatial urban pressure analysis of the Giza Pyramid Plateau in Egypt, 18 p.
2011-44	Andrea Caragliu Chiara Del Bo Peter Nijkamp	A map of human capital in European cities, 36 p.
2011-45	Patrizia Lombardi Silvia Giordano Andrea Caragliu Chiara Del Bo Mark Deakin Peter Nijkamp Karima Kourtit	An advanced triple-helix network model for smart cities performance, 22 p.
2011-46	Jessie Bakens Peter Nijkamp	Migrant heterogeneity and urban development: A conceptual analysis, 17 p.
2011-47	Irene Casas Maria Teresa Borzacchiello Biagio Ciuffo Peter Nijkamp	Short and long term effects of sustainable mobility policy: An exploratory case study, 20 p.
2011-48	Christian Bogmans	Can globalization outweigh free-riding? 27 p.